ECONOMIC BOTANY

Devoted to Applied Botany and Plant Utilization

Vol. 2 JANUARY–MARCH, 1948 No. 1

Semi-Popular Articles

Technical Literature Reviews

Utilization Abstracts

By the editor

ECONOMIC BOTANY
Devoted to Applied Botany and Plant Utilization

Founded, managed, edited and published by

EDMUND H. FULLING

of

The New York Botanical Garden

Economic Botany is published quarterly. Subscription price per annual volume everywhere is \$5.00; price per single copy is \$1.50. Subscriptions and correspondence may be sent to the office of publication, N. Queen St. and McGovern Ave., Lancaster, Pa., or to Economic Botany, The New York Botanical Garden, New York 58, N. Y., and checks should be made payable to Economic Botany. Typescripts should be double-spaced. Photographs will be considered only if of high photographic quality.

Published Quarterly one volume per year, January, April, July and October, at North Queen Street and McGovern Avenue, Lancaster, Pa.

Entered as second-class matter March 12, 1947, at the post office at Lancaster, Pa., under the act of March 3, 1879.

ECONOMIC BOTANY

Devoted to Applied Botany and Plant Utilization

Volume II
1948

Founded, managed, edited and published by
EDMUND H. FULLING
at
The New York Botanical Garden

Published Quarterly
Printed at North Queen Street
and McGovern Avenue, Lancaster, Pa.

CONTENTS

Semi-Popular Articles

Technical Literature Reviews

Utilization Abstracts

ECONOMIC BOTANY

Devoted to Applied Botany and Plant Utilization

VOL. 2 JANUARY-MARCH, 1948 No. 1

Semi-Popular Articles

Technical Literature Reviews

Utilization Abstracts
By the editor

Important Corrections. In ECONOMIC BOTANY, Vol. 1, page 437, fourth line, insert "other plants," before the word "seventeen". Note also on page 110 of this issue, the supplementary data for Dr. Hocking's article in Vol. 1.

Economic Botany—*A Modern Concept of Its Scope*[1]

No longer limited to descriptions of economically important plants and to accounts of their culture, products, preparation, occurrence, distribution and uses, the scope of Economic Botany today must include careful taxonomic work, the application of physiological principles, recognition of ecological relationships and the science of genetics.

F. RAYMOND FOSBERG
U. S. Department of Agriculture

Introduction

In almost any environment where man finds himself, except the open sea, the Greenland or Antarctic ice-caps, or the barren wastes of downtown city streets, plants and plant products form the most obvious part of his surroundings. The food he eats, the beverages he drinks, the materials he uses, with the exception of metals and stone, almost all have their origin in plants. An otherwise almost unbelievably dreary landscape is relieved by plants; they take care of the accumulation of carbon dioxide which man and other animals exhale, releasing the oxygen for re-use; they cause many of the diseases with which man is afflicted; they provide cures for many of these same diseases and others; and they provide many of the materials with which he performs his daily work and play. They touch him at every point in his life in one way or another.

The study of the plants that affect man in any way is Economic Botany in its broadest sense. This broad concept involves a consideration of the mutual relationships of plants with each other, with animals and with other aspects of their environment.

[1] This paper is the introduction to a projected text-book on economic botany.

Scope, Limitations and Relation to other Sciences

In a classical sense Economic Botany is a descriptive science dealing with plants useful or noxious to man, their products, characteristics, uses, geographical origin and distribution. Other points of contact between plants and man, and other phases of knowledge of economic plants have usually been excluded as belonging to other sciences. Sometimes certain interesting features of the culture or exploitation of various species are given attention, as well as occasional commercial statistics.

For a broader understanding of the relationship between plants and man it is desirable to study, in addition to the classical descriptive Economic Botany, certain general features of other plant sciences as they touch on economic plants and on man's dependence on plants. The detail in which each can be considered is necessarily limited, but technical detail may well be left to the respective sciences themselves, and only the broad outlines and relations included in Economic Botany.

There is much of plant physiology, mycology, bacteriology, genetics and ecology that does not pertain directly to man, as there is much of agriculture,

ecology, soil conservation and forestry that bears little relationship to plants. However, these sciences all, as well as plant breeding, horticulture, plant geography, evolution and even certain phases of economics bear a very definite and close relationship to Economic Botany. They form much of its very substance in the sense in which it is treated here.

Classical Economic Botany

Although no longer to be regarded as the whole content of the science of Economic Botany, the simple study and description of economic plants, their culture, products, preparation, uses, occurrence and distribution still must remain the basic material of the science. Without the fundamental information provided by this study, the more modern and specialized branches cannot exist as fields of a science. Writings and studies on agriculture, horticulture, ethnobotany, microbotany, forestry, grazing, phytopathology, genetics, plant breeding and conservation are mere idle discussion without adequate and correct knowledge of the plants concerned. Classical Economic Botany, supplemented by careful taxonomic work on economic plants, supplies this information.

The basic information essential to further work on any economic species or plant group comprises: (1) its structure and description; (2) its exact identity; (3) its relationship with other groups of plants or its position in the plant kingdom; (4) the classification of its subdivisions; (5) its place of origin; (6) its distribution, both natural and with the aid of man; (7) the conditions under which it thrives; (8) the essentials of its culture; (9) its uses or detrimental features; (10) the preparation and nature of its products; (11) the commerce or industries to which it contributes or of which it forms the basis. Of course, not all of these categories apply necessarily to all economic plants. The classes of information thus outlined form the substance of classical Economic Botany.

Here is the logical starting point for the formulation of the more advanced problems of plant science in its relation to man's economic activities. It is in the light of this information that the application of the findings of other branches of botany to these problems and to general human needs and welfare can be made.

The problem of the exact identification of economic plants and their parts has long been a preoccupation of economic botanists. Pharmacognosy, dendrology and seed analysis, as well as important sections of systematic botany, systematic mycology and systematic bacteriology have developed in response to this necessity for exact determination of identities of economic plants. Refined techniques and methods of examination and study have been developed for this purpose. Unbelievably minute fragments of plants may often be named with certainty. However, the most painstaking study can yield no more accurate identification than is permitted by the state of the taxonomy of the group of plants concerned.

Taxonomy of Economic Plants

Taxonomy is the science of classification. The taxonomy of plants has been likened to a street directory that enables us to find our way around in the plant kingdom. It has also been likened to the framework upon which all other knowledge of plants is arranged in such a fashion that it may be readily found when needed. A secondary, but very important, function is to provide names for the kinds of plants.

When one considers that there are between 200,000 and 300,000 species of plants known, it is easily seen that the task of providing a usable directory or

an adequate framework, or even distinctive names, is no small one.

When one considers, further, that these tasks have been done gradually by many different workers of varying ability and background, and that during the process there have been vast and deep changes in the underlying biological philosophy and enormous increases in information, it is a wonder that any coherent structure has been achieved. Nevertheless, we have a usable classification that is being improved constantly.

Considering their importance, the taxonomy of the outstanding economic groups of plants is in an astonishingly backward condition. In many groups it is practically impossible to get an unqualified identification of an economic species or determination of the parentage of an economic hybrid. An investigation into the literature on many economic genera shows little but confusion, careless work and lack of understanding.

There are many reasons for this, not the least of which is the intrinsic difficulty of many of the groups, resulting from hybridization and modification under cultivation and selection.

Another important reason has been the scarcity of able taxonomists with an interest in economic groups. Most economic botanists have the quality, unfortunate if it resides in systematists, of being more interested in the applications and uses than in the plants themselves. The taxonomic botanists have tended to avoid economic groups with their myriads of hybrids, segregates and perpetuated abnormal forms. The result has been that the taxonomy of economic plants has largely been done by pharmacists, foresters, horticulturists, phytopathologists and other practical men, ill-fitted, both by lack of training and by lack of real interest, to do systematic work.

The outstanding exception to this in America is the remarkable Liberty Hyde Bailey who might well be called both the dean of American systematic botanists and the dean of American horticulturists. His books, such as the "Manual of Cultivated Plants" and the "Standard Cyclopedia of Horticulture," have long been the basic works on cultivated plants. His "Gentes Herbarum" is the outstanding serial publication devoted largely to them. The Bailey Hortorium of Cornell University, founded by him, is the acknowledged center for systematic work on cultivated plants. He, himself, has done an enormous amount of systematic investigation of both wild and cultivated groups. The outstanding need of the systematic botany of cultivated plants is for more men of Bailey's ability, energy and breadth of interest.

Of course, the classification of economic plants is in no way distinct from that of any other plants. It cannot be, and the confusion will not lessen until any idea of distinction and any basic difference in methods and approaches is abandoned. It would be well if the general taxonomists and herbarium curators, as well as the economic botanists, realized this and broadened their concepts accordingly. It would also be well if those practically interested in plants would realize that the systematist is working toward a classification that portrays the actual relationships of the groups of plants, and that the annoying name changes are the inevitable result of increasing knowledge and the correction of past errors.

Wild and Cultivated Economic Plants

All economic plants or their ancestors were once wild. The pattern of the history of a useful plant seems to be one of first utilizing the wild plant until scarcity or greatly increased use makes it imperative or economic to increase the natural supply or to bring it within more easy access. Then follow attempts to cultivate and domesticate it. Concur-

rently go the processes of improvement and acclimatization, basically by selection, in more modern times by breeding. Knowledge as to soil and climate preference and cultural characteristics accumulates. Inevitably diseases and insect pests make their appearance. Methods of avoiding or combatting them must be developed.

Often, because of good returns, more of a given plant product is produced than can be used. Competition for a market ensues. This stimulates efforts to improve the plants by breeding, to increase production by application of various scientific procedures, and to find new uses for the product.

Of course, this sequence goes on at different rates for different plants. The origin and early history of the majority of important economic species is obscure or unknown. Ames has suggested (Economic Annuals and Human Culture, p. 8, 11, 1939) that many of them may have evolved almost along with man. Their history is only slowly being deciphered. Others, such as rubber, *Cinchona* and many ornamentals, are very recent additions to the domesticated flora. Some, such as chicle, sarsaparilla and many timbers, are still in the stage of exploitation of the wild plants. Doubtless the pressure of economics will change this situation, unless substitutes are found.

The final stage in the history of many economic species is their disappearance, due to the discovery of superior species or cheaper substitutes.

Ethnobotany

The study of the uses of plants by primitive man is called "ethnobotany". It is equally a branch of botany and of anthropology. To carry out successful investigations in this field a person must have a background in both sciences. Certain ethnobotanical works show conspicuously the lack of training of their authors in one field or the other.

The uses of plants by primitive man divide themselves roughly into three classes—for food; as materials for making implements, houses and other necessities; in medicine and magic. Some uses, such as poisoning fish and personal adornment, do not fit too well into any of these, but may be considered with the second.

The importance of food plants in the diet of primitive man varies from group to group. In the culture of the Eskimos and other hunting peoples plants have little place. With pastoral peoples, plants are of importance as food for their animals, which in turn are food for the people. Some tribes, on the other hand, are strictly agricultural. There are all shades of intermediates between these. Wild plants, too, enter in various ways into the diet of primitive people. A related use is as fuel for cooking and warmth.

Plants are one of the most obvious sources of materials for making things. Wood is so plentiful and easily worked that its use is almost universal, and its uses are without number. Vines are used for tying. Leaves are widely used for thatch. Plant fibers are used for cordage and textiles. Vegetable dyes are known to most peoples. Fish-poisons are of wide-spread use, as are arrow-poisons.

The uses of plants in medicine and magic are almost limitless. Most, of course, are without any physiological significance. Even the origins of the uses are obscure, except where there is a real or fancied resemblance to a part of the body or other significant object. However, occasionally investigation shows a true physiological basis for the use of a primitive medicine. Several have become important even in modern materia medica. Others might, if carefully experimented with.

The study of plants as a key to the migrations of people in prehistoric times

is a fascinating and increasingly important phase of ethnobotany. Both the present distribution and the occurrence, as archeological remains, of particular species and races of plants give important clues to past contacts and lack of them between peoples. The same study often yields information as to the origin of certain domesticated plants and as to the time and place of their domestication.

Another important phase of ethnobotany, and one that is also of great importance in tracing relationships and migrations of peoples, is the study of various techniques of using plants and plant materials. Styles of weaving and plaiting of fibers, of tying knots in cordage, of building houses, of making canoes, and even of preparation of foods are usually quite distinctive and show evolutionary change and cultural diffusion patterns. The presence of plant motifs in sculpture and ornamentation is often a clue to plant uses and cultural contacts. Much may even be learned about the habits and relationships of completely extinct peoples from the archeological remains of plants in their village sites.

Agriculture and Horticulture

Agriculture and horticulture are, as the names would suggest, the culture of plants on a field and a garden basis, respectively. In horticulture the individual plant is the object of attention, while in agriculture the aggregate or the crop is the object.

Historically, in the development of any economic plant, the horticultural phase usually comes first. Then, in the case of plants that are destined to become of major importance, agricultural methods and techniques are usually developed. The two points of view may be contrasted in the fact that horticultural success is largely dependent on personal knowledge and understanding of plants by the gardener or horticulturist, while success in agriculture is largely a matter of engineering and scientific management. Small farming is a combination of both approaches.

Production of grains, sugar, many herbaceous fruit and vegetable food plants, forage, fiber plants, many vegetable oils, cellulose, tobacco, *etc.*, may be regarded as agriculture. The growing of orchard crops, garden vegetables, other food plants on a small scale, and ornamentals, is mainly horticultural. Both are essential features of our civilization.

Applied Plant Physiology

It is hard to circumscribe the part of plant physiology that should be definitely associated with economic botany. Most parts are potentially applicable in agriculture or industry. Yet much of the work that is done is definitely pure science. Much, also, that passes as plant physiology is not botany at all but chemistry.

Work on the application of fertilizers and related subjects is definitely economic. So also are the various lines of research on problems connected with the storage and bleaching of fruits and vegetables.

Much of the research in applied mycology and bacteriology is physiological in nature and is closely tied to agriculture and industry. The relationship between plant physiology and plant pathology is so close in places that there is no dividing line. In fact, most problems in plant pathology are definitely physiological in nature, and their solutions, too, are physiological. Deficiencies and other unfavorable environmental conditions are the direct causes of many diseases, and by lowering the resistance of plants to parasites, they are indirectly the causes of others. The physiology of the causal organisms is frequently the key to their control.

Problems of tolerance, drought resistance, reaction to acidity and alkalinity and others of similar nature are basic in agriculture. The investigations in these lines are usually of a non-practical nature, but the results are equally of interest to physiology and to agriculture.

The whole subject of plant hormones and growth substances has become of increasing practical importance, as in the matter of weed-killers, retention or dropping of leaves on fruit trees, rooting of cuttings, and many other definite applications.

The conditions for germination of seeds, scarification, vernalization, dormancy periods of weed seeds, reaction of young plants to sun and artificial light, and other related subjects interest the agriculturist and horticulturist fully as vitally as the physiologist.

From these examples, chosen among many, it becomes plain that for a broad knowledge and effective command of economic botany a good understanding of general plant physiology is most essential. Physiology is one of the subjects where fundamental science and practical application are inextricably entangled.

Plant Indicators

The problem of detecting, classifying and evaluating all the factors which affect plant growth in an environment has so far defied the ingenuity of even the best plant ecologists and physiologists. It is so complex that even the complexity is hard to grasp. Yet intelligent land utilization demands some understanding in this direction.

It is obvious that the behavior of plants themselves will provide the best key to a knowledge of at least the results of the total of these factors. A trial-and-error method, often used, is to try out one crop after another on a piece of land. This is costly, time-consuming, and often may lessen the usefulness of the land while mistakes are being made. A more effective method, employed in simple form for ages, is to observe the wild plants and vegetation types which occupy the land. It is plain that these are equally subject to the same factors that affect the growth of cultivated plants.

Wild plants and vegetation types have evolved their characteristics in response to certain combinations of environmental factors. Different species and different vegetation types have developed in response to different combinations of these factors.

The requirements of cultivated plants are fairly well known. Their behavior in certain types of situation is known also. A study of the original vegetation of localities where a given crop has succeeded, as well as of those where it has failed, will give a fair indication of where to try it in the future. A locality with vegetation similar to that where the crop in question has succeeded, and with identical species, is obviously more likely than any other.

Certain families, genera and species are known to be inhabitants, ordinarily, of certain types of soil, climate or other environment. The Ericaceae, for example, are known to demand an acid soil, while most Chenopodiaceae grow in alkaline localities. Therefore, it would be obviously foolish to try to raise blueberries in places where *Atriplex* is the dominant plant. *Pyxidanthera*, *Hudsonia* and *Xerophyllum* indicate extremely acid and sterile sand. Such lands are therefore better left in their original pine forest, as attempts at agriculture are predistined to failure.

There are certain plants which are unpalatable to livestock. *Ranunculus acre*, various *Croton* species and various wooly Malvaceae are examples. These plants ordinarily do not increase unduly in competition with grasses in a pasture. However, if the pasture is overstocked

and areas of soil are eaten or trampled free of grasses, these plants immediately gain a foothold and, not being eaten, increase rapidly at the expense of the useful grasses. The presence of large numbers of these plants on a pasture or range is a certain indication of overgrazing. Careful observation will detect any increase in this type of plant early and will enable the livestock man to regulate his stocking to suit the capacity of his pasture.

Such examples of plant indicators could be multiplied endlessly. These are sufficient to suggest the possibilities.

Weeds

Weeds are pioneer plants, those which are able to invade and occupy new or disturbed habitats. They are characteristic of the earliest stages in the succession of revegetation of denuded lands.

Since agricultural lands are essentially denuded areas, weeds naturally invade them, and so persistent and successful are they that combatting them is often a major agricultural problem. A great amount of research has been done on the matter of weed-killing, and remarkable advances have been made.

Although the major objection to weeds is that they offer competition to cultivated plants and that they are too often successful in this competition, there are other problems also. Some of them are poisonous to livestock or humans. Some are hosts to noxious insects and plant - disease - producing organisms. Others are spiny and unpleasant. Still others have fruits that entangle themselves in the hair of animals and must be removed, or they lower the quality of wool. Sometimes they are actually so irritating that they cause sores. Their seeds get mixed with those of crop plants and reduce the value of the crop seeds. In pastures they often tend to displace plants that are more palatable or nutritious to livestock. This condition, however, often indicates an over-grazed, over-stocked or poorly managed pasture.

On the other side must be reckoned the value of weeds in protecting denuded soil that, for any reason, is lying fallow. Were it not for this protection, the condition of the world's soils would be much worse, even, than it is.

Forestry

Practically all except some of the purely engineering phases of forestry are botanical in nature. Forestry deals with trees growing under natural rather than horticultural or orchard conditions. In nature, trees ordinarily grow close together over large expanses. This type of vegetation is called forest. Trees also are a feature of savanna, grassland with scattered trees, and very occasionally occur as solitary individuals. The distribution of forest, savanna, grassland and desert is largely controlled by climate. In a region characterized by a truly forest climate, revegetation after destruction of the forest tends to produce forest again immediately or in a relatively short time.

The earliest stage in the development of forestry is the exploitation of natural forests. The important products of the forest are timber, wood-pulp and, in some countries, fire-wood and charcoal. Minor products are such things as tanbark, dye-woods, maple-sugar, turpentine, rosin, gums, waxes, balata, chicle and, before they became cultivated crops, rubber and cinchona bark.

In the natural course of any exploitation of forest resources, men being greedy as they are, the resources begin to become exhausted and the products to be scarce. In civilized countries this acts as a stimulus to the study of the forests, resulting in a certain degree of understanding of forest ecology. This makes possible forest management, regulated harvesting and protection from fire

and other destructive agencies. Though the natural forest still remains, it is made to yield regular crops. This aspect of forestry begins to be a form of agriculture.

The next logical steps are restoration of forest to lands that have been denuded—called reforestation—and the creation of forests where none have been before, often on worn-out agricultural lands—called afforestation. These processes are likely to succeed only when administered with considerable knowledge of the environment and of the climatic and soil requirements and other characteristics of the trees that are planted.

To supply seedling trees for reforestation and afforestation programs, where these are done other than by scattering seeds, nurseries are necessary. Here again much information is necessary as to the requirements of the seedlings of various species of trees. Whole plantings have failed for lack of the proper mycorrhyzal fungus in the soil. A rather unexpected factor often enters in the different behavior of seedlings of the same species but from different regions.

One of the hazards of forest nurseries as well as of field plantings of trees, or even occasionally of natural forests, is epidemic disease. There are innumerable tree diseases, caused by fungi, bacteria, viruses and even physiological factors such as deficiencies. Forest pathology is a well developed and important branch of phytopathology, and, of course, of economic botany. The obstacles to control of forest diseases are many. While spraying may be practical in the nursery, it seldom is so after the trees are planted out. Mixed planting, resistant strains of trees, and insect control are some of the methods used. The forest pathologist should be a good forest ecologist as well, to have a proper understanding of his work.

The utilization of forest products is also properly associated with economic botany; in fact, it bears a close relationship to classical economic botany. A great deal of plant anatomy and plant biochemistry, as well as a general knowledge of the actual uses of forest products, enter here. The subject of wood technology is a specialized branch of economic plant anatomy, as well as of engineering. Many problems of cellulose structure are of fundamental interest to the wood-pulp industry. Latex production and latex characteristics are equally important to the rubber, chicle, gutta percha and balata industries.

Perhaps the greatest importance of forests is as watershed cover. Without a continuous water supply man cannot live. Forests, by acting as sponges, causing water to be absorbed into the earth, tend to hinder rainwater from running off immediately. This both insures a continuing ground-water supply and prevents destructive erosion and floods. The problems of watershed management are basically problems of plant ecology. With skillful management, a forest can serve as a watershed, a source of forest products, a refuge for game and other wild animals and plants, and a valuable recreation ground.

Soil Conservation

A consideration of forestry and watershed cover naturally leads to the subject of soil conservation, of which many aspects are botanical.

The only effective means of soil protection is by maintenance of a vegetation cover to impede run-off, prevent erosion and maintain the soil in a condition to absorb water. A fertile soil is dependent on an appreciable humus content which is maintained by continual deposition of dead leaves and plant parts, which in turn can be practically provided only by vegetation. The nitrogen content of the soil is sup-

plied by the leguminous plants in the vegetation which harbor bacteria in their roots that fix atmospheric nitrogen.

Under appropriate conditions either grassland or forest vegetation may protect the soil. Proper management is dependent on a knowledge and understanding of plant ecology. In a grazing country such understanding results in proper stocking to maintain a firm turf which resists erosion very effectively. Lack of it often results in overstocking, with consequent overgrazing and soil destruction. In forest lands, as mentioned above, proper understanding also should lead to good management.

In agricultural lands the problems are more of an engineering nature, though knowledge of the effect of various plants upon the soil, and the maintenance of strips of vegetation, as well as checking erosion after it is started by proper planting, are related to economic botany.

Microbotany and Plant Pathology

The economic aspects of microscopic plants are many and diverse. If bacteria and fungi are admitted to be plants, many familiar fields become a part of economic botany. Most are generally regarded as separate sciences, but a familiarity with them is essential to a broad concept of economic botany.

Bacteriology and mycology have their medical phases, the study of plants that actually attack man and cause disease. Bacterial diseases are well known. Those caused by fungi are less familiar but often are just as serious. Related, of course, is the study of such organisms that attack other animals. The study of those that attack plants, phytopathology, is doubly a part of economic botany. It is not possible to overestimate the importance of this branch, as plant diseases, if uncombatted, by destruction of his food supply, could easily sweep man from his dominance of the earth. Among the primary approaches to control of plant diseases are the discovery, selection and breeding of resistant varieties of plants. However, the evolution of races of pathogenic organisms proceeds at such a rate that the fight is continuous.

Another important branch of microbotany is the study of the bacteria and fungi that inhabit the soil and the roots of plants. Many of them are the common decay organisms. Their importance and usefulness may be appreciated by contemplating the volume of unconsumed dead organic matter under which we should be buried in a short time if all such organisms were removed. Soil fertility, moreover, is maintained very largely by their activities in combination with those of nitrogen-fixing bacteria. The decomposition of vegetable matter to form humus and to release minerals essential to plant growth is a process fundamental to the whole balance of nature. The fixation and oxidation of nitrogen by bacteria is another, equally important process.

A field of great practical importance is that of the microbotany of water. The purity of a water supply involves a study and understanding of algae, such as the Myxophyceae and diatoms, as well as bacteria. Water may be rendered unpalatable by undue multiplication of algae as well as unsafe by bacterial pollution. The former condition may, however, be an indication of the latter. The purification and disposal of sewage, especially in septic systems, is also a matter of the activities of microorganisms, especially bacteria.

Finally, microscopic plants are becoming increasingly important as the bases of industrial processes. Cheese-making, brewing, bread-making, wine- and liquor-making have been important for ages, and are directly dependent on the activities of fungi, yeasts and bacteria. There are also many other fermented foods used in various parts of

the world. More recently the making of industrial alcohols, carbon-dioxide, acetic acid, lactic acid and other chemical products of fermentation has assumed tremendous importance and volume. Antibiotics, by-products of fungus metabolism, which exert a bactericidal effect, have, in the last several years, become fundamental to medicine. Yeast is a source of vitamins. Industrial microbiology has thus become a very significant field of economic botany.

Genetics and Plant Breeding

The applied aspect of plant genetics, commonly termed "plant breeding", has been a deeply important subject since before genetics began, when it was on a purely empirical basis. It must be recognized that here is one of the most basic branches of economic botany, and one that touches many other branches.

Plant breeding is concerned with the production of races or hybrids of economic plants that are superior in one way or another to the wild or previously existing domesticated ones. Breeding may be for increased yield of whatever product is concerned, for higher or special qualities of any sort, greater vigor and hardiness, adaptation to differing habitats, peculiar or beautiful appearance in ornamentals, disease resistance, or any other desired feature within reason.

The plant breeder utilizes the hereditary variability of plants, their mutations and their capacity to hybridize to accomplish his results. He applies the principles formulated by the geneticist in managing these characteristics to achieve his ends. He takes advantage of natural mutations and now uses colchicine, X-rays and atomic radiation to produce mutations at will. The process is, basically, directed evolution.

The principal source of the variability needed and of the desired characteristics for plant breeding is in the wild relatives of the plants worked on. Here the classical economic botanist, the plant taxonomist and the plant explorer are called in, as it is one of their functions to accumulate and record information about the characteristics of the plants of the world. One of the obstacles to the progress of plant breeding is that the plants of most regions are so poorly known. Most people are astonished when they discover how incompletely explored is the world with regard to its plant resources. It is also a sad truth that many of these resources are being destroyed and lost before they are even discovered or before they can be utilized. A reason for the conservation of wild plants wherever possible that is not often advanced is this matter of maintaining reservoirs of genetic variability and useful characters for use in future plant-breeding work. The lust for "development" of unused areas might well be tempered by consideration of this aspect of conservation.

It has long been plain that there is no basis for predicting which of the plants not now used will prove useful later. This becomes more of a truism when genetic characters for use in plant breeding are considered. Worthless weeds which have economic relatives become the source of the genes for disease resistance, cold tolerance or increased vigor which the breeder wants to insert into the heredity of his new improved horticultural plant or field crop.

Another source of characters for use in plant breeding is the great array of varieties of many crops cultivated by primitive people. For example, a great search by corn breeders for maize varieties cultivated by remote Indian tribes is taking place in tropical America. The corn specialist has learned to be on the alert for any possible different variety with its additions to the available supply of characters. It is impossible to tell when some of these obscure varieties will

provide a much needed factor in the development of a new hybrid.

Unfortunately the varieties of cultivated plants maintained by primitive peoples tend to disappear as these peoples come in contact with more advanced cultures. Well-known varieties that are in some way superior tend to replace them. Once lost they can never be recovered or replaced. A valuable function of agricultural institutions should be to maintain collections of such varieties of cultivated species. Unfortunately such institutions do not usually have enough continuity of interest and stability of administration to carry on such an activity successfully.

The modern study, sometimes termed "biosystematy", the detailed investigation of the structure, relationships and cytology of natural populations within a species or genus, is showing great promise as a method in this branch of economic botany. For example, a thorough knowledge of the characters, chromosome numbers and distribution of even the smaller populations of *Vaccinium* in the eastern United States makes it possible for the blueberry breeder to know exactly where to go for any desired factor, and gives him a pretty good idea as to what climates will favor any given combination of these factors. Blueberry breeding is now in a position to proceed in a thoroughly scientific and efficient manner to exploit to the limit all of the potentialities inherent in the part of the genus *Vaccinium* thus studied.

Biosystematy is essentially a study of the processes and results of natural evolution. The obvious outcome of the acquisition of such a thorough understanding of natural evolution must be the principle of directed evolution. This, of course, is what any plant breeding program is, in a primitive way. Thorough familiarity with the principles and processes involved, as well as with the materials available, will enable the breeder to decide exactly what result he wants and to lay out a program that will achieve it with a minimum of effort and expense. The old trial-and-error method of simply crossing two things and awaiting what happens will gradually become a thing of the past, as intensive biosystematic studies become more and more common. The obstacles are the amount of work and expense involved and the amount of ability and persistence required of the investigator.

Applied Paleobotany

Paleobotany, as well as animal paleontology, has always had its major economic importance in stratigraphy. Plant fossils, at least those of higher plants, are less common than those of animals, except in the form of coal. However, they are often quite diagnostic. Since the economic geologist is often confronted with the problem of tracing and identifying strata and formations, the data of the paleobotanist assumes distinct economic significance. In the petroleum branch of economic geology, fossil diatoms and often the fossils associated with coal beds are of great importance.

The whole subject of coal and peat formation is of interest economically. Coal is definitely a product of plant fossils. Some theories consider petroleum to be a by-product of coal formation, others that it is a result of fossilization of enormous quantities of diatoms, still others that it is formed when coral-reefs are fossilized. All of these, even coral-reefs, are botanical matters (coral-reefs are as often formed of calcareous algae as of corals). Amber and kauri-gum are fossil plant resins.

Recreational and Aesthetic Values of Conserved Areas of Natural Vegetation

The amounts of money spent each year by people camping in the woods and mountains justifies consideration of the

matter of recreational and aesthetic values of plants by the economic botanist.

The rapidly increasing number of people who seek the restful influence of the out-of-doors effectively answers the person who cannot see a patch of standing timber, swamp or other wild land without considering it waste land. It is the country with tall trees and undisturbed meadows that calls and attracts the person worn out by the hurry of modern life, not the logged-off, burned-over or subdivided land. Many people, though of course not all, derive a tremendous aesthetic satisfaction as well as effective rest from a day, week or month in natural, undisturbed surroundings. This will doubtless become more and more true as the tempo of modern life increases and its complexity grows. Most unfortunately, however, at the same time the area of undisturbed country is decreasing and retreating farther and farther away. This fact is important to consider.

Since plants and vegetation form the most important features of wild country, the economic botanist may be surprised to discover that this matter is a primary concern of his. He, along with the other outdoor scientists, may be in a position to offer some of the answers to the problem of counteracting the effect of modern life on the human nervous system.

Summary

The scope of the science of economic botany is considered to have broadened from the simple accumulation of information as to the identities, properties, uses and distribution of economic plants, to include now any area where plant science impinges on the economic life of man. The inclusion of phytopathology, plant breeding, agriculture, horticulture, much of forestry, plant ecology, bacteriology, mycology, and soil and nature conservation may seem to stretch the science of economic botany beyond all recognition. However, if it has the effect of revitalizing a rather decrepit branch of botany, the attempt will be justified. At least it will provide a focus that will serve to show the actual relationship of a number of apparently distant subjects.

Utilization Abstract

Chemurgic Research in Florida. In 1941 the State Legislature of Florida established the Florida Engineering and Industrial Experiment Station as part of the University of Florida at Gainesville. There in eight buildings and under a staff of 107 persons, investigations are being conducted, among other subjects, on the utilization of Florida plants and plant products, especially with relation to naval stores, pulp and paper, tung oil, citrus processing and sugar. The problems involved include: *a*) Improving the technique of spraying a film of sulfuric acid on new incissions in the bark of pine trees whereby increases of more than 100% in the production of gum have been obtained. *b*) Investigating the possibilities of commercially obtaining tannin from the bark of the abundant scrub oak in the State. *c*) Better utilization of citrus-press water resulting from pressing citrus pulp prior to drying in rotary kilns. Much of this water is now evaporated to "citrus molasses" used for cattle feed. In recent years the solid waste materials—peel, rag, seeds—remaining after juice extraction, has been converted into cattle feed—more than 100,000 tons in the 1945–1946 season. *d*) Utilization of the 21% protein in the press cake of tung seeds, after oil extraction from them, in synthetic fibers, firefighting foams, plastics, *etc.* (*R. D. Walker, Chemurgic Digest 6(10): 161. 1947*).

Economic Uses of Lichens

Some of these lowly plants have long served as fodder for the reindeer herds of Lapplanders, while others have been the sources of industrial dyes, as those used in the manufacture of Harris Tweed cloth.

GEORGE A. LLANO
Henry Shaw School of Botany
Washington University, St. Louis, Mo.

Introduction

THIS article is a general discussion of most of the economic uses of lichens. A more detailed account, including the biology of lichens, was published by the present author (13) in 1944, of which this treatment is a revision of the economic uses only. Neither of these papers is complete but merely an attempt to bring together some of the information regarding utilization of lichens, and a working bibliography for those who have little familiarity with lichenology. None of this material is available in text-form; most general texts mention lichens in the most perfunctory manner, citing references only from older texts which give little credit to modern studies.

Though other branches of the botanical sciences have received considerable impetus from the activities of research in recent years, little of this force has carried over into the science of lichenology. Lichenology is not a popular study. It is reserved to a few specialists throughout the world whose studies are largely in the realm of lichen taxonomy, geography and ecology. To the few who have investigated the chemical and physical as well as physiological structure of lichens, all lichenologists owe much for the stimulation which they have given to the science. Among these recent contributions attention should be directed especially to that of Quispel (14).

Biology of Lichens

Lichens can be distinguished by their habit of growth as crustaceous, fruticose or foliose. The first form is the most simple, on bark, wood, rocks or soil; the other two forms are more intricate, often erect, branched or leaf-like, usually with a dorsal and a ventral surface but in some species merely circular. These plants are widely distributed from the arctic to the tropics, consisting of thousands of species and innumerable varieties and forms. They have one feature in common that distinguishes them from all other plants. Each of them consists of two different and separate entities living together in such a balanced relationship that they not only form a successful organism but are able to reproduce the unit. One component is a fungus, usually an Ascomycete but in a few cases a Basidiomycete, whose intertwining, compact hyphae give form to the thallus. The other component consists of a species of green or blue-green alga enmeshed between the hyphal strands of the fungus. In this combination, each component is able to extend its activities into habitats that would be inimical to it as an independent organism. Together they form a particular species of lichen with specific morphological, taxonomic, ecologic and sometimes physiologic characteristics, the fungal part growing by

extension of its hyphae, the algal cells by division of themselves.

This intimate relation of fungi and algae is usually regarded as one of symbiosis, *i.e.*, of mutual benefit to each component, the fungal element deriving food from the green algae, and the algae benefitting by having its moisture and mineral nutrition maintained through the water absorption and water retention characters of the fungus. The presence of fungal haustoria, however, and the penetration of hyphae into the algae have been cited as evidence that this relationship is merely another case of parasitism; the algae can live independently but the fungi can not.

The morphology of the reproductive system is the chief basis of all taxonomic treatments of this group with the inevitable result that many mycologists have segregated the various groups among those fungi that appear to have a close relationship. However, the thallus is a specialized type of structure, and the fungus-alga relationship makes possible specialized functional relationships peculiar only to lichens. They may be conveniently treated as a homogeneous group, for they have their own literature and specialists who concentrate their studies wholly on them.

The fungal components of lichens reproduce sexually by means of ascospores, or basidiospores, depending on the type of fungus-symbiont present. When these spores germinate, however, growth cannot continue unless the resulting hypha happens to come in contact with the particular species of alga necessary for its development into the kind of lichen from which it arose. A more common method of propagation, and perhaps the more successful, is asexual. This may be merely by broken pieces of the thallus body being blown or carried elsewhere, or by detachment of a minute mass of hyphae enclosing algal cells from specialized structures known as "soredia"; this secondary method of reproduction is not found in all species of lichens. Lichens have been synthesized in a few cases by bringing together the two component parts.

Mosses are often mistaken for lichens. The two should never be confused, however, for mosses possess a stem and leaves which are never found in lichens. On Pacific Coast trees there may be found *Ramalina reticulata*, a lichen of great beauty, often called "Spanish Moss" from its pendant habit of growth. This term "Spanish Moss" is more often used commonly for similar hanging plants on the trees of the southern States, though here, again, in error, for those plants are not mosses but members of a seed-bearing plant family, the Bromeliaceae.

Lichens as Food for Invertebrates

Certain studies (19) concerning invertebrates known to feed partly or wholly on lichens include the feeding habits of mites, caterpillars, earwigs, black termites, snails and slugs. Invertebrates apparently feed on all but the most gelatinous lichens which have almost complete immunity because of their slimy covering. Dry hard lichens are rarely attacked, although it has been noted that two species of snail graze on the endolithic lichens *Verrucaria* and *Protoblastenia*, mainly on the thalli and the apothecia. Excrement from these snails contained fragments of calcium carbonate and green algal cells, while the hyphae and dead algal cells were apparently digested. Experiments have shown that snails will feed on potatoes covered with cetraric, rhizocarpic and pinastrinic acids, poisonous to other animals, but will not feed on vulpinic acid which is recognized as poisonous to vertebrates. Bitter-tasting lichens, treated by a soda method to extract the acids, were acceptable in preference to fresh untreated but moist-

ened lichens. This is of interest, since there is a widely current assumption that lichens are remarkably well protected against attacks from animals by reason of these acids.

Free living algae are the preferred food of invertebrates, in most cases, but when not obtainable, the gonidia, *i.e.*, the algal layers in the lichen thallus, are taken. Hué (13)[1] presented the opinion that the abundance of lichens in Arctic regions results from the comparative absence there of snails and insects. Not a few "new" species of lichens have been the result of insect and snail ravages, further modified by plant regeneration.

Lichens Used as Fodder

Non-grassy Ranges. This subtitle refers specifically to range lands which are composed primarily of lichens or which are used at definite times of the year for grazing because of the lichen vegetation. Such areas are rarely entirely free of sedges, grasses, herbaceous plants, low bushes and sphagnum bogs. When this type of vegetation is at its best in spring and summer, it has little value as non-grassy range land. These areas lie north of the tree line and above timber line but may extend well down into the timber along mountain sides. They are best developed in sub-Arctic regions but may extend into the temperate zones. They cover those parts of Greenland which are ice-free and still have sufficient moisture for plant growth, Iceland, northern Scandinavia, Siberia, Alaska, the Northwest Territories of Canada, Labrador and the archipelago of the Arctic Sea. As a whole, the thousands of square miles composing this area furnish non-grassy range feed in the winter for wood buffalo, musk-ox, caribou and other wild herbivores and for domesticated reindeer, as well as a grassy range feed at all other times. It is not to be assumed from this statement that all these wild species of animal are entirely dependent on lichen forage for winter grazing. Actually, too little is known of their food preferences to permit a definite statement.

In the Antarctic regions, though lichens are the predominant plants, they are not so richly developed as in the Arctic. Due to absence of herbivores in this area, further discussion of it will be omitted. The extreme southern part of South America, Tierra del Fuego and lower Patagonia might also be included in this classification. Santesson of Uppsala, Sweden, has related to the author that when he was botanizing in the Argentine during the late war, he was approached by government officials requesting advice on the practicability of importing reindeer into those regions for the use of the natives. Santesson's opinion, based on his thorough knowledge of lichen species and of reindeer culture, indicated that the South American lichen species of the area under consideration, although probably acceptable to reindeer, were not abundant enough to sustain them. A news report of Oct. 20, 1947, however, stated that 20 reindeer have been imported into Argentina for stocking the Tierra del Fuego area. These are to provide food, clothing and transportation to the 3,513 inhabitants of the archipelago, and are part of the Plan Quiquenal "which will make Tierro del Fuego a magnificent exponent of social and economic progress. . .".

Reindeer have been introduced, apparently with some success, for the more stable support of Eskimos in Alaska and northern Canada and also as straight commercial ventures. This emphasizes the value of non-grassy ranges. A report of 1929 by the United States Department of Agriculture in Alaska states that there already is danger of over-grazing

[1] Citations in the present author's original article (13) are not repeated in the bibliography of the present article but are to be found in the former.

in those areas where reindeer have been introduced. This is a problem that the Lapp herders recognize and meet by keeping their herds on the move during the critical winter period. Reindeer require constant care and the use of knowledge which is a basic part of the old Lapp culture. If the Eskimos are capable of assuming this responsibility and of applying to these animals the principles which they may have observed in caribou, an experiment of this kind is sure of some success. The caribou and the old world reindeer have similar habits, feeding on lichens in snow-free areas or pawing away the snow cover to obtain better grazing. In summer they migrate into the highlands, partly to avoid insect pests and partly to feed in fresh pastures. The constant movements of caribou during the winter period throughout their range and during the spring and summer from the lowlands to the highlands prevent overgrazing in any one part of the feeding range.

Lapp culture is primarily a reindeer culture, so specialized in its application that the Lapps have derived their own Lapponian terms for varying types of reindeer grazing lands and lichen species which they differentiate sharply, no mean feat in itself. The living problems of present day Lapps arise mainly from the fact that some of them have given up their nomadic habits and hence their main source of revenue, reindeer herds. The Norwegian, Swedish and Finnish governments are conscious of their responsibilities toward these people and of the importance of helping them maintain their culture, and so they encourage lichenologists to make studies and surveys of the lichen flora in those countries.

Reindeer have a market value of from

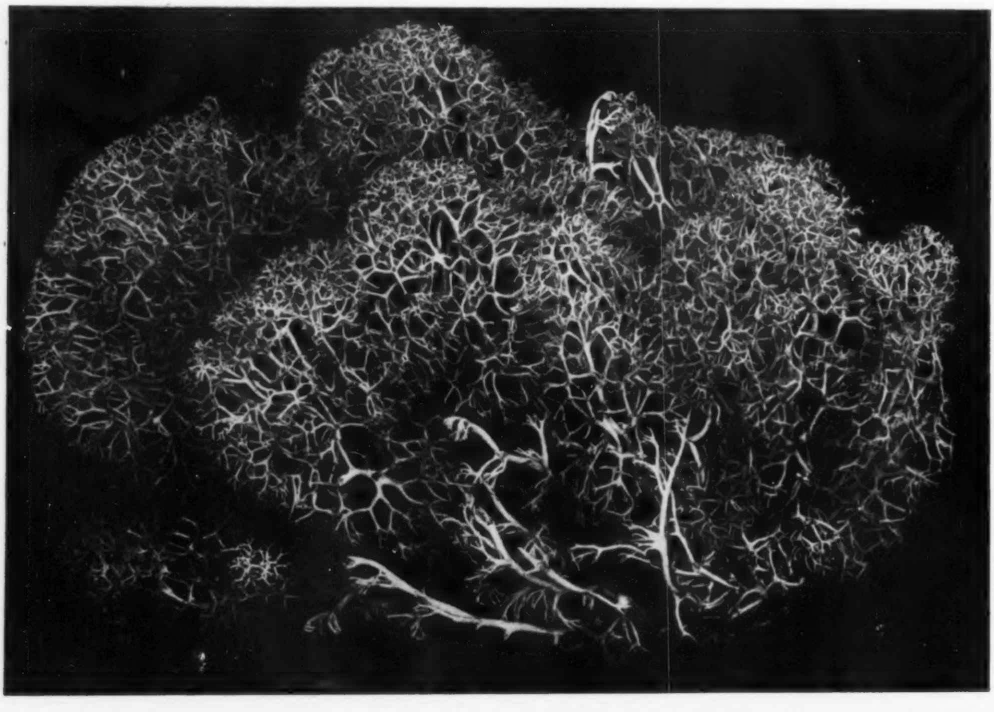


FIG. 1. Reindeer moss, *Cladonia alpestris*. This species and *Cl. rangiferina* constitute the principal food of reindeer and caribou herds. (*Courtesy The New York Botanical Garden.*)

200 to 300 Swedish Kroner (3.60 sw. kr.= $1.00, Aug. 1947), and it is not unusual for a Lapp to possess several thousand animals; such a person can hardly be considered indigent. Reindeer meat is unrationed and is served throughout Fennoscandia. The hide is used for leather goods and, with the hair, is manufactured into footwear and a high quality sleeping bag. During the war German troops stationed in Finmarken slaughtered reindeer indiscriminately for meat and hides.

Reindeer culture is not peculiar to the Lapps but prevails also among other nomadic tribes inhabiting lands bordering the Arctic Sea from Murmansk across and down into Siberia. This is partly indicated in a study (8) on the chemistry of under snow fodder for winter pastures of reindeer in the U.S.S.R. The United States Government and the Canadian Government have embarked upon a program of wholesale importation of reindeer into northern areas without consulting or encouraging lichenological studies or surveys as a basis for selecting non-grassy range lands for the highest relative pasture capacity. The possibilities for survival on northern submarginal lands is greatly enhanced by the proper use of these lands for reindeer grazing.

The most useful species for grazing are the so-called reindeer lichens, *Cladonia rangiferina* Web., *Cl. alpestris* Rabenh. and *Cl. sylvatica* Hoffm., though the last is sometimes said to be refused by reindeer. Probably others, *e.g.*, species of *Cetraria, Stereocaulon* and *Alectoria*, are accidentally or preferably taken, since they are found growing with the former. The Cladoniaceae are the most important, for they grow in carpet-like masses to a height of six inches. Their dependence on the substratum is not clearly recognized, since they grow almost equally well on all available areas, especially after fire, competing with and preventing the development of certain seedlings. They may be covered for long periods by snow, but the animals that are accustomed to feed on them are capable of finding them under snow cover. The use of lichens as accessory fodder has always received attention in northern Europe in times of forage (wild or cultivated hay, grain, *etc.*) scarcity, and in some regions the plants are regularly used for this purpose.

Lynge (13) presents his own and other investigations concerning the food value, harvesting methods and growing habits of lichens in relation to the feeding habits of reindeer and cattle. He states that in 1916 the large lichen fields of Finmarken maintained 100,000 head of reindeer, resulting in a serious overgrazing problem. Smaller fields in other Norwegian provinces supported 50,000 of these animals. To remedy these conditions, regulations prohibiting reindeer pasturing were put into effect where necessary until good growth was reëstablished. Under conditions of unrestricted grazing, lichen vegetation may be seriously altered, while mere trampling by large herds in small areas will destroy these plants. Under such a situation fields of *Cl. alpestris* may be invaded by less desirable *Stereocaulon paschale* Fr. which produces full grown thalli in five to six years after which *Cl. alpestris* again becomes dominant.

In Lynge's account there is a list of Lapponian lichen terms indicative of some of the peculiarities connected with reindeer husbandry. The Lapps differentiate between lichens and mosses, since reindeer never feed on the latter. "Jaegel" refers to field lichens on which reindeer fatten; "Gadna" occurs on stones and trees and are eaten if no other food is available; "Lappo" are the beard forms growing on trees for which the animals have great fondness. The Swedish government permits the Lapps to cut down birches in winter emergen-

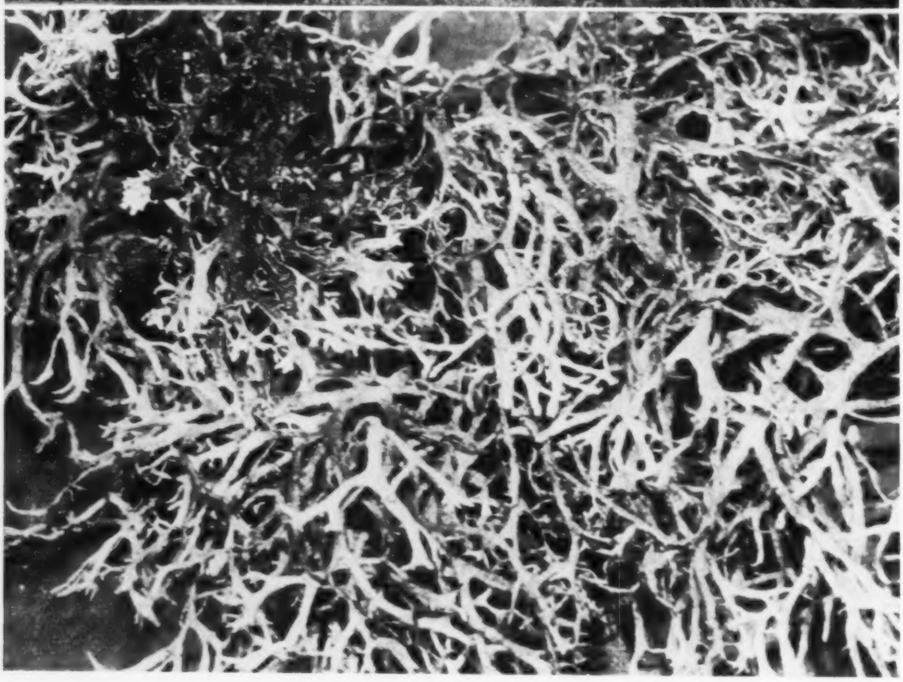


FIG. 2 (*Upper*). Rock tripe, *Umbilicaria papulosa*, with pustules on its upper surface, and two other species of *Umbilicaria* on the rock. Mt. Desert Island, Maine, U.S.A. This and other kinds of rock tripe, *Gyrophora* sp., have been used by polar explorers as emergency food.

FIG. 3 (*Lower*). *Evernia furfuracea*, showing upper and lower surfaces of the thallus. Mt. Desert Island, Maine, U.S.A.

cies to enable the reindeer to get at this type of feed. The herders also recognize the pasture cycle after fire with its successive lichen formations. Reindeer feed on the younger parts or tips of the plants.

The relative abundance of these economic lichens would be best stated as "generally common", for solid areas of any one species is the exception rather than the rule. *Cetraria islandica* Ach. in average areas yields about 700 kilo of air-dried "moss" per sq. km. *Cl. alpestris* gives higher yields, and selected areas in northern Norway have produced 1,400 to 1,500 kilo per 1,000 sq. m.

Harvesting is performed by hand or hand implements; this is for the use of domestic animals only, for even the Lapps keep goats or a cow in addition to their reindeer. Among the Lapps the work is performed by the women and by hand, a method considered conserving and cheap, since only a quarter of the quantity growing is thus garnered, leaving enough for regeneration. The Norwegian method, using rakes with 15 cm. teeth, takes up to two-thirds of the amount available. Sticks are shaken out, and the adhering soil may be separated by water. Dry "moss" is brittle and to avoid large losses is most economical when having a water content of 40 to 70% by weight. As the plant is gathered it is piled into small heaps (40 to 50 cm. high) with a branch of birch in the center for a handle. These small heaps are brought together to form large bundles. They are moved around on sunny days in the field when the water content may go down from 60% to 30%, and are then placed in straw-covered shelters. Otherwise they are taken to a drying house in winter in sledge loads of from 300 to 600 kilo. The crop may be further dried in a warm ventilated room and stored when the water content has gone down to 14% of the dried weight. Hand presses are unpopular because of their cost and weight. Transportation costs for this type of forage is considered expensive, and the forage is never transported far.

One cause for occasional friction between the Lapps and the Scandinavians in these northern areas is the more thorough harvesting methods of the latter which have caused the Lapps to complain of loss of grazing areas. Reindeer crop the lichen close but leave enough of the thallus for future growth and the possibilities that the area can be pastured again within four years. Hand harvesting or implement harvesting uproots the lichen thallus, and it may take ten or more years for regeneration and growth. This situation has been alleviated by regulations imposed by the local governments. Lichens on trees may be scraped away and gathered in sacks by non-Lapps.

A farmer having ten cows and some sheep and goats uses yearly 60 sledge loads of lichens for his stock. This implies a need of 4,800 to 18,000 sq. m. of well covered lichen fields per year. Since these plants may require up to 30 years to regenerate a marketable stand, a farmer must have access to 150,000 to 560,000 sq. m. of land. This land must be preferably mountain or heath land, since forest areas contain objectionable pine needles and sticks. However, few farmers give so much lichen fodder to their cattle, actual amounts depending on the quantity of grass available. In "moss" districts three to five sledge loads are collected per cow. It is possible for one man to gather from 50 to 100 kilo. by hand per day or with implements to increase this up to 300 to 400 kilo. per day. Even in older times it was difficult to get laborers for gathering lichen fodder, due to the small pay, and it was necessary for the State to intervene. School classes were encouraged to collect, receiving three ore

per kilo per student and one ore per kilo for the teacher (4).

As an additional food for domestic animals, especially swine, lichens are of value, and Lynge recommends greater use of svinamöse (swine-moss) for these animals. Jacobj (13) found that young pigs throve better on a combination of reindeer moss and ordinary feed than with the latter alone. He also satisfactorily fed rabbits and hares with *Evernia prunastri* Ach. after extracting the acids. Icelanders feed *Cetraria islandica* to their cattle, pigs, and ponies. It has also been reported good for oxen, while the richness of the milk of the small cows of northern Scandinavia is attributed to this food. An early traveller relates that during a period of famine in Finmarken, the farmers preferred to feed *Cetrara islandica* to their cattle than to use the lichen themselves for food but risk the loss of their cattle. Cows were given 10 kilo, horses 6 to 8 kilo, swine 2 to 3 kilo, and sheep and goats 1 to 2 kilo daily (4).

FIG. 4. Reindeer, summer-feeding in Lappland, Sweden. (*Courtesy Swedish Railways*).

Nutritional Studies. The nutritive value of these non-grassy range feeds apparently lies in their high lichenin (lichen starch) content. Hesse (13) worked out a comparison of the sugar content of lichens with that of potatoes and found that for *Cetraria islandica* the proportion was 1 of potatoes to 3.35 of lichen; for *Cl. rangiferina*, 1:2.5. The former has been found to yield 61% carbohydrates and other products of its hemicelluloses. The bitter principle, due to the presence of lichen acids in even the mildest of these plants, can be removed in order to make the fodder more palatable to domestic animals. This is done by soaking them in water for 24 hours or by addition of potassium carbonate to the water for quicker action. Boiling with lye, after which the lichens are thoroughly rinsed with water, is the usual method of preparing the plant for human animal consumption. Sometimes the lichens are mixed with hot water and straw or meal, and salted before being fed to cattle; the proportion of meal and salt is gradually reduced until the cattle become accustomed to the lichen alone. One kilo of *Cl. rangiferina* (15 to 18% water content) is considered to be equal to one third poor fodder or early grass. By analysis this lichen is found to contain 1 to 5% proteins, the rest carbohydrates and little or no albumen(4).

Russian investigations of the under-snow fodder from winter pastures at the Saranpaul State Reindeer Farm indicate that winter herbage is rich in crude fats and in nitrogen-free extracts, and that the content of fiber and hemicellulose is higher in winter than in summer herbage. Chemical study of winter and summer lichen herbage showed a higher protein than fat content, particularly in *Alectoria jubata* Ach. (7.77%) and *Umbilicaria pennsylvanica* (6.27%) which varied with the season(4).

Use of lichen fodder in Europe goes back into antiquity, as indicated by prehistoric remains found near Lake Constance in Switzerland (19).

Lichens Used as Food by Man

History. From the earliest times the food of man has included lichens, sometimes as a delicacy, but more often as a last resort in the face of starvation. Their commercial importance however, as food for man, has decreased, though Hanstien, chief lecturer in the Agricultural School at Aas, Norway, long ago prophesied that lichens are destined to become the great popular food for the masses because of their cheapness and nutritive value. The use of lichens for human food has been revived at times, and they were recommended in Sweden as substitute food in 1826, 1841 and 1868 after bad frosts and droughts had affected regular crops. In general, the bitter principle in these plants gives them an unpleasant flavor, and unless removed, exerts an irritating effect upon the digestive tract of man, causing inflammation.

Cetraria islandica probably rates first as lichen food for humans. It is gathered commercially in the Scandinavian countries and in Iceland and sold on the market as "Iceland Moss". Schneider says of this "moss": "Inhabitants of Iceland, Norway and Sweden mix this with various cereals and mashed potatoes from which an uncommonly healthful bread was prepared". Lynge (13) quotes a tradition "that there was no starvation at Modun in 1812 as long as there was brodmöse (bread-moss) left in the forest". Icelanders made the most of lichens as food for humans, collecting great masses of this plant yearly. Two barrels of clean lichens pressed down gave the equivalent of one barrel of the usual grain meal. From this flour they made bread, gruel, porridge, salads and jelly in various ways. Milk was added, and in this form the lichen was the basis of various light

and easily digested soups and other delicacies said to be of value for dyspeptics. It was also mixed with flour in making a non-friable ship's bread which was less subject to weevil attack than ordinary bread. In northern Finland, in times of famine, reindeer moss and rye grain were made into a bread having a taste like that of wheat bran but leaving a sense of heat on the tongue.

Before use the lichen was boiled with lye, rinsed in clear water, dried and placed in closed containers which were stored in a dry place. In this fashion it would keep for many years. For bread-making it was first oven-dried, then ground fine; one fourth grain meal was next added, and the mixture was baked as usual, producing a strong bread with a fair taste which kept well in storage. *Cetraria islandica* was also mixed with elm cortex as well as with grain and boiled with a surplus of water to produce a broth. *Cetraria nivalis* was occasionally used in the same manner. For porridge, a cooking container was filled with one third *C. islandica* and boiled with water three or four times, stirring frequently until it became thick. The top broth and scum were skimmed off and the rest salted according to taste. This was permitted to cool until hard, then eaten with or without milk. It could be redried in an oven and used for bread. As gruel, about one pound of the finely cut lichen was added to one and a half to two quarts of water and cooked slowly until about one half of the water had been evaporated. This was strained while hot and flavored with raisins or cinnamon. After boiling, and separating the broth, the residue was eaten with oil, yellow of egg, sugar, *etc.*, as a salad, "and the most pretentious person will like it". The hardened jelly of this lichen was often mixed with lemon juice, sugar, chocolate, almonds, *etc.* (4).

The biblical manna of the Israelites appears to have been *Lecanora esculenta* Evers. (19) which is still eaten by desert tribes, being mixed with meal to one-third of its weight. This lichen grows in the mountainous regions and is blown loose into the lowlands where the thalli pile up in small hummocks in the valley. As late as 1891 there was an abundant fall of this "manna" in Turkey. The Turks are recorded as using *Evernia prunastri* for jelly (4); the ancient Egyptians also used this lichen and *E. furfuracea* Mann in making bread (13). There is still some importation of these lichens from Europe as fermentative agents, and Forstal in the 19th Century reported seeing several consignments from the islands of the Greek archipelago bound for Alexandria. In India (17) *Parmelia abessinica*, "Rathipuvvu", is used as food, generally in a curry powder, and medicinally; while in Japan *Umbilicaria esculenta* is considered a delicacy and sold as "iwa-take" or "rock mushroom". Because of the scarcity of collecting places and the difficulty of access, the market price is relatively high. In France lichens are used in the manufacture of chocolates and some pastries; the lichenin is, in this case, merely used as a filler and a substitute for commercial starch.

The American Indian's knowledge of wild food plants included the use of *Alectoria jubata*, though there are indications that some of the more primitive Pacific coast tribes made greater use of these plants. "Tripe de Roche" or "Rock Tripe" was so named by the French "courreur de bois" of boreal America who used it in periods of emergency. Franklin recorded it in his diary as the main course of many a meal. This "Rock Tripe" is one of the Umbilicareae and must be treated with boiling water or at least soaked before being eaten. Franklin's use of this lichen has been quoted many times, though the complete report states that the species used caused severe illness. This was

probably the basis for the recommendation to personnel of the United States Army Air Forces during the war for its use under emergency conditions in Arctic areas. It may be noted that members of the Franklin Expedition were also boiling and eating the leather of their equipment. Under such starvation conditions any type of food or plant may be used in an attempt to allay hunger. But under a preplanned program designed to educate personnel with a minimum of out-of-door experience and no knowledge of plants suitable in such eventualities, a greater emphasis of the more common vascular plants and of the animals in these regions would have been more applicable towards the preservation of life. Lichens are not easily recognized, and their preparation with fire presumes the accessibility of fuel which may not always be available. Future recommendations must be based on more thorough research studies.

Nutritional Studies. Scientific investigations regarding the digestibility of lichens and the behavior of lichen substances in the body have been too few, but the evidence at hand does not agree entirely with the fact that these plants have been used extensively as foodstuffs. Analyses have shown that they contain a variety of carbohydrates of which polysaccharides are the most common, giving rise on hydration to several sugars, some cellulose, chitosan, glucosamine and inulin. Of these the only compounds directly available in intermediate metabolism are the simple monosaccharides, *i.e.*, six-carbon sugars. Polysaccharides apparently need to be split into "physiological" sugars before they become available to the body. Uhlanders and Tollens (13) noted a difference in the occurrence of characteristic carbohydrates in various lichens examined, though they all contained some lichenin. Thinking that the substances in *Cetraria islandica* and *C. nivalis* were similar, Poulsson (13) made a bread from these two species to determine their use in diabetes mellitus. Though 46 to 49% of the carbohydrates of the former species was digested, the latter species caused such intestinal disturbances that the experiment had to be discontinued. Brown (13) failed to induce glycogen formation in rabbits by feeding them lichenin obtained from *C. islandica.* Ordinarily neither amylytic enzymes nor hydrochloric acid (0.3 to 0.5%) have any noticeable effect on lichenin, while iso-lichenin is, at most, converted into a dextrin-like form without producing

FIG. 5. Reindeer pawing away snow cover to obtain lichen fodder. Lappland, Sweden. (*Photo by G. Haglund*).

sugar; the action of bacteria yields acetic, propionic, butyric and lactic acids.

More recently Wallerstein (13) fed mice white bread, later replacing it with lichenin, and showed the latter to be 53 to 64% utilized. Similarly Shimizer (13), in determining the influence of some polysaccharides on the protein balance of a dog, found that they were digestible and available foodstuffs in the alimentary canal. Later he digested polysaccharides *in vitro,* using extracts of macerated intestine and pancreas in an 0.8% NaCl solution, but found no monosaccharides. He took this as evidence that there are no enzymes in the digestive system of mammals capable of

splitting inulin, lichenin or hemicelluloses. On determining the action of fecal material and fermentative bacteria on these substances, Shimizer and Tonihide (13) concluded that they are split into sugars by the bacteria in the digestive tract of mammals and can then be absorbed.

It has been assumed in the past that the presence of the enzyme lichenase in the stomach contents of the ox and pig probably enables these animals to convert lichenin into the more digestible sugars. The action of snail lichenase on lichenin *in vitro* has been found to produce cellubiose and lichosan, an anhydride of glucose similar to cellosan, a product of cellulose. Messerle (13) states that the livers of snails contain much lichenase which converts cellulose to sugar. Jewell and Lewis (13) had found this to be true of many invertebrates, suggesting that the ability to hydrolyze lichenin may be characteristic of invertebrates only.

Swartz (13) questions the value of algae and lichens as sources of energy in nutrition. Oshima suggests that they may be valuable for their inorganic salts, while Prausnitz (13) calls them "faeces-forming foods" in that they stimulate intestinal activities. Most of Swartz's studies were on the algal components, yet she was able to draw certain conclusions concerning those chemical substances which are common to both components. They were:

a) Nutritive studies of lichens would indicate that as energy-producers their value is not appreciable. Yet the fact remains that certain animals do feed upon them and thus sustain themselves in regions where energy and high body heat are prerequisites of life. The assumption follows that our understanding of the value of lichens as fodder is still incomplete, though ruminants are apparently more effective users of hemicellulose than other animals.

b) Aerobic and anaerobic bacteria, not enzymes, are responsible for conversion of hemicelluloses into sugars. The amount available to the animal system is extremely diverse, depending on the animal and the lichen species.

Vitamin Studies. Blix and Rydin (13) found that *Cladonia rangiferina* contains some ergosterol, more than most lichens, but the content is low in comparison to that in yeasts and molds. This same species collected in Uppsala in August and September showed only traces of Vitamin D.

Feeding experiments with rats failed to show Vitamin B or G in either of two samples of short and tall lichens obtained in Alaska. Short-growth lichens gave more Vitamin A and less Vitamin D than tall-growth types. Short-growth types appeared more palatable to rats. Unfortunately the names of the lichens used were not indicated, so that this evidence is only of the most general interest. Bourne and Allen (13), using acetic acid-silver nitrate reagent for Vitamin C, obtained a positive test in lichens.

Medicines and Poisons Derived from Lichens

The name "lichen" (= Leprous), originally applied to hepatics, is of Greek origin and was used by Theophrastus in his "History of Plants" to describe a superficial growth on the bark of olive trees. Dioscorides applied it to true lichens because of their resemblance to the cutaneous disease for which they were supposed to be specific.

History. The use of lichens in medicine can be traced back to antiquity. *Evernia furfuracea* has been found in an Egyptian vase from the 18th Dynasty (1700–1600 B.C.), and is still imported into Egypt from Europe and sold with *Cetraria islandica* as a foreign drug. The Egyptians also used this species of *Evernia* to preserve the odor of spices employed in embalming mummies; it

has been identified in one such body (500–800 B.C.) by Edward Tuckerman who noted the similarity of this species to that occurring in Maine.

In the 15th century A.D. there was throughout Europe a constant attempt to follow the guidance of nature in the study and treatment of disease. It was believed that Providence had scattered here and there on plants "signatures" of resemblances more or less vague to parts of the human body, or to diseases to which man is subject, thus indicating the appropriate specific. This era climaxed the commercial importance of these plants, for never before or since have they played such a unique role in the world of economic plants. The long filaments of *Usnea barbata* Web. were used to strengthen the hair, though Hippocrates also prescribed it for uterine ailments. The natives of the Malay Peninsula still use a closely related species for treating colds and strengthening after confinement (13). *Lobaria pulmonaria* Hoff. was the suitable remedy for lung troubles. Boerhaave (19) regarded it as an excitant, tonic and astringent, and recommended it for hemorrhages and asthma. *Xanthoria parietina* Th. Fr., being a yellow lichen, was supposed to cure jaundice, while *Peltigera aphthosa* Willd., the thallus of which is dotted with small wart-like tubercles, was recommended for children who suffered from "thrush". Other species of *Evernia*, *Peltigera*, *Parmelia*, *Cladonia*, *Roccella* and *Pertusaria* were used as purgatives or to control fevers, diarrhea, infections, skin diseases, epilepsy and convulsions. *Pertusaria communis* DC. was especially interesting in that it was used to cure intermittent fever, having less action on women than men. *Peltigera canina* Willd., as a cure for hydrophobia, was sold by a Dr. Mead as the celebrated "Pulvus antilyssus" (Dillenius, 1741). The so-called drug "Lichen quercinus virdes" consisted mostly of *Evernia pru-*

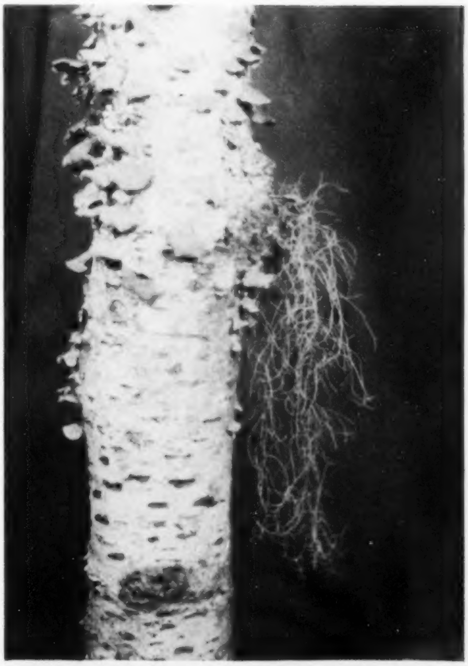


Fig. 6. (*Upper*). Beard lichen, *Usnea* sp., growing on birch, Mt. Desert Island, Maine, U.S.A.

Fig. 7 (*Lower*). *Parmelia physodes*, showing its dense growth on the branch of a pine tree. Mt. Desert Island, Maine, U.S.A.

nastri, E. furfuracea and *Parmelia physodes* Ach., (19). The doctrine reached the height of absurdity in the extravagant value set on a lichen found growing on human skulls. "Mucus cranii humani". This skull lichen (*Parmelia* or *Physcia?*) fetched its weight in gold as a cure for epilepsy.

Luyken, in his "Historia Lichenum in Genere", Göttingen, 1809, gives a long list of medicinal "Lichenes, quorum usus obsoletus est". Plitt (13) recommended more emphasis on the study of lichenology to pharmacognosists, venturing the opinion that the medical virtues of bark drugs may be affected by the lichens growing on them. Feé dealt earlier on this subject in a beautifully illustrated treatise (7).

"Iceland Moss" was given an important place in medicine by Linnaeus in 1737. It has been used in chronic affections as an emollient and tonic, and it would indeed have been a "Divine gift to man" had it lived up to all its prescriptions. Today it is employed as a substitute for salve bases, in the preparation of emulsions, the reduction of the bitter taste in certain drugs, as a laxative and as a culture medium in laboratory technique. With the exception of this lichen, all have been replaced by more effective modern drugs so far as medicinal use is concerned.

Physiology. The physiological action of the cetraric acid of "Iceland Moss" has been studied by Kobert (13). It has no poisonous effect either when injected into the blood or when taken into the stomach of small animals. Small doses induce peristaltic movements in the intestines. Large doses may injure an animal, but if given as free cetraric acid it passes through the stomach unchanged to become slowly and completely dissolved in the intestine. The mucous membrane of the intestine of animals that had been treated with an overdose was found to be richer in blood, so that Kobert assumed that cetraric acid would be useful in assisting digestion. There is also the possibility that the lichen acid inflamed the sensitive mucous membrane. By means of acetone, d-usninic, evernic and obtusatic acids have been extracted from *Ramalina calicaris* (13). The last named acid was the same as "Makao" obtained from the Manchurian drug, "Shi-hoa".

Lichens, with two exceptions, are nonpoisonous, though some acid substances in others may be irritating when taken internally. The poisonous exceptions are *Evernia vulpina* and *Cetraria pinastri*, both a characteristic bright yellow. The former contains vulpinic acid in the cortical cells, the crystals of which are yellow in the mass. The latter species and *Cetraria juniperina* Ach. produce pinastrinic acid in the hyphae of the medulla, and the crystals are orange or golden-yellow. These lichens have been used in northern European countries to poison wolves by stuffing them and powdered glass into bait (18). Santesson isolated the crystalline acid and tested it on animals; it produced respiratory difficulties, reducing the rate of breathing until death ensued.

More recently a report of the Wyoming Agricultural Experiment Station on a study of the presence of selenium in soil and various plants states that *Parmelia molliuscula* Ach. contains this poisonous salt in sufficient quantities to affect sheep and cattle. It produces a lack of coordination of the hind limbs; in severe cases the animals are unable to move either hind or fore legs. Other examples of lichens containing such elements include beryllium in *Parmelia saxatilis* Ach. and *Xanthoria parietina* Th. Fr., chlorine in *Evernia furfuracea* (13).

Modern Developments in Lichenology. Employment of lichens as raw materials in pastries, confectionery,

foods, and in the production of alcohol depends largely on the properties of "lichen starch". The presence of a certain number of phenols, acid-phenols and acid-phenol-ethers, together with other substances in the extracts of some lichens, forms the basis of their use in perfumery and cosmetics. The tinctorial properties of lichens are for the most part derivatives of orcinols, as in species of *Roccella*. Besides possessing lichenin and isolichenin and the sugar alcohols such as erythritol and manitol, lichens have as their most characteristic components the lichen acids which seem to be built on an altogether original pattern. In the past 50 years more than 200 of these lichen acid compounds have been isolated. These compounds are, for the most part, known only from the Class Lichenes and were originally thought to be peculiar to them alone. Raistrick (15) introduces new findings, however, remarking that the isolation of two lichen acids, parietin and physcion, from the lower fungi is an ". . . observation . . of some biological interest since . . . . (it) gives strong evidence for the view that the so called lichen acids owe their origin to the fungal half of the the fungus-alga symbiont.—The presence of chlorine containing metabolic products (of the Lower Fungi) emphasizes the close metabolic relationship between moulds and lichens, since two of the very few organic chlorine-containing substances occurring in nature have been isolated from lichens, *i.e.*, gangaleoidin and diploicin". Research on lichen acids began with the Germans —Zopf, Hesse, Fischer and others—but

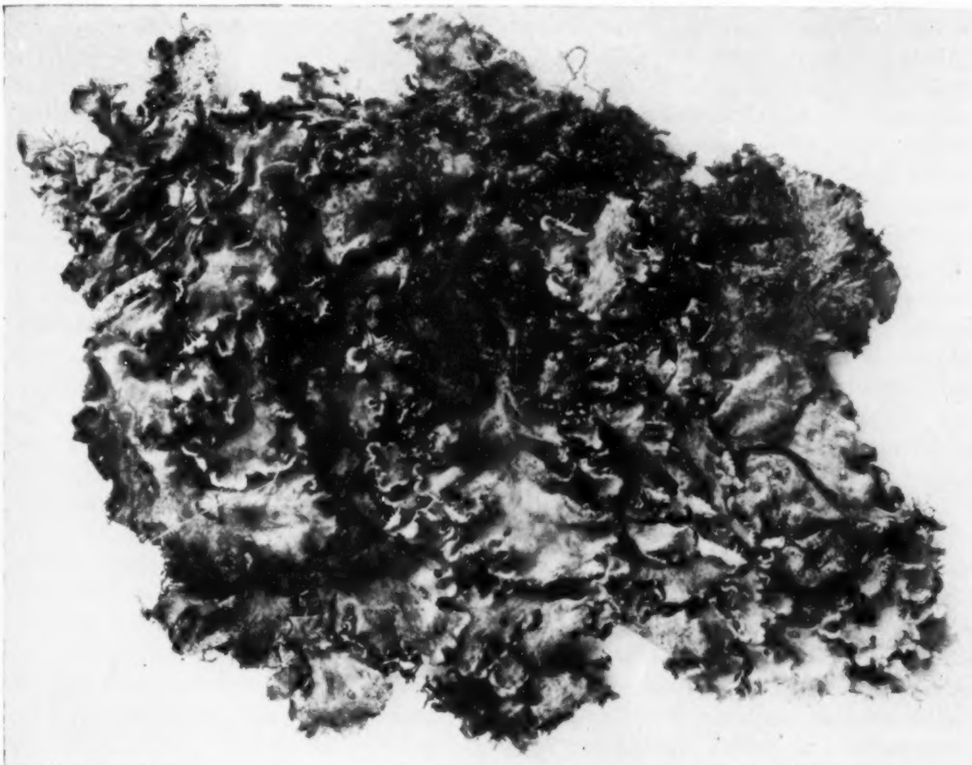


Fig. 8. Dog lichen, *Peltigera canina*, preparations of which were regarded in the Middle Ages as efficacious in treating rabies. (*Courtesy The New York Botanical Garden*).

received most attention from the work and simplified methods of extraction of Asahina and his Japanese colleagues. These studies are being continued today by Sao, Sastry and Seshadri of Andhra University, Waltair, India, and by the workers at University College, Dublin, Ireland—Breaden, Davidson, Hardiman, Jones, Keane, Murphy and Nolan—who are contributing detailed information on the chemical constituents of the lichens in their respective areas. The research of these workers is basic to the recent experimental aspects of lichenology. In view of present day research, this information has passed from the sphere of academic interest and begins to assume real value in practical application as well as to present a more complete understanding of the biology of this group of plants.

Since the discovery of the chemotherapeutic effects of penicillin, the phenomenon of antibiosis has attracted widespread attention and stimulated the investigation of other plant groups. Some investigators (2), studying the antibiotic activity of lichens, proceeded with their studies on the basis that since the "antibacterial activity of the green alga *Chlorella* and the many antagonistic substances known to be produced by numerous kinds of fungi, the lichens seemed to offer favorable material for antibiotic investigations inasmuch as lichens . . . consist of algae and fungi". Using the cylinder plate procedure, they analyzed the antibacterial activity of extracts from 42 species of lichens, later extending the work to 100, of which 27 species were found to be active against *Staphylococcus aureus* and *Bacillus subtilis*, while four species inhibited the growth of *Proteus vulgaris* and *Alcaligenes fecalis;* none of the lichen extracts used in the test showed antagonism against *Escherichia coli*. That more than one antibiotic compound may exist in lichens is suggested by the fact that both *S. aureus* and *B. subtilis* are inhibited by extracts from *Cladonia Grayi*, *Parmelia physodes* and other lichens, while substances obtained from some species of *Cladonia* inhibited *B. subtilis* but not *S. aureus*. Extracts from *Cladonia furcata* Schrad., *Cl. papillaria* Hoff. and *Umbilicaria papulosa* inhibited *S. aureus* but were inactive against *B. subtilis*. Furthermore, the inhibition of some Gram-negative bacteria by selected species of lichens lends further support to the theory of multiple substances. The authors pose the question:—Do the characteristic lichen acids possess antibacterial activity or are the antibiotic properties of lichens related to traces of other unidentified substances synthesized by these plants? Burkholder and his associates noted that some of the lichen compounds possess certain structural features in common with antibacterial substances isolated from molds, but they could not be sure that these were responsible for the antibiotic phenomena observed. They point out the fact that "almost nothing is known about the anabolism of the components or the roles of the various substances formed in the lichen body". In a subsequent report, Burkholder and Evans (3) reach the conclusion that "the phenomenon of antibiosis . . . is well exemplified in the lichens". These antibiotic substances are apparently different from penicillin, for the activity of several species of lichens was not lost after boiling in Na_2CO_3 solution. Samples of lichens collected from different regions showed, on the whole, characteristic activity in antibiotic tests with suitable bacteria. No explanation is offered for the variability, though there may be some relationship between this phenomenon and the fact that some of the diagnostic lichen acids vary in different samples of some lichen species. Though diagnostic compounds known to occur in the antibiotic species of *Cladonia* are listed, the authors suggest that other unidentified substances

might be responsible for the observed antibacterial properties. The presence of antibacterial substances in numerous species of *Cladonia* and in representatives of other genera of lichens appears to be definite, but whether these are bacteriocidal or merely bacteriostatic is not proven. Although Gram-positive bacteria, including several pathogenic types, are inhibited, Gram-negative bacteria, with a few exceptions, are generally not susceptible to the antibiotic substances of lichens.

Other research (1*a*) on anti-tubercular compounds indicates another promising possibility for a lichen compound. Numerous acids were the subject of synthetical studies by various workers in the field of anti-tubercular compounds. Barry began with roccellic acid isolated from *Lecanora sordida* Th. Fr. The author states: "We have already reported that this substance in the form of its half-esters or half-amides inhibits completely the growth of the tubercle bacillus *in vitro* at a dilution of about 1/500,000". Barry adds that "the most active of these compounds are at the moment being tested in animal protection experiments, and although they are strongly antagonized by serum *in vitro*, they seem to have some activity in the animal".

Industrial Uses of Lichens

Brewing and Distilling. Use of lichens instead of hops for the brewing of beer has been mentioned as having occurred in one or more monasteries of Russia and Siberia which had a reputation of serving bitter but highly intoxicating beer to the traveller. Tuckerman further describes a by-product of *Lobaria pulmonaria* Hoff. when it was used as "a yellow, nearly insipid mucilage which may be eaten with salt".

Alcohol production from lichens is an old art, now replaced by increased cultivation of potatoes, importation of sugar and distillation of wood. Preparation of spirits from lichens was recommended in 1870 as a means of saving grain otherwise diverted into alcohol production. It was claimed that 20 pounds of lichen would yield five liters of 50% alcohol. Stenberg (20) published a report in Stockholm in 1868 on the production of lichen brandy, and included detailed plans for setting up a distillery with figures of possible production levels. By 1893 the manufacture of brandy from alcohol derived from lichens had become a large industry in Sweden, but by 1894, as a result of the local exhaustion of the plants, the industry languished. Arendt (13) in 1872 reported that this originally Swedish discovery was being applied in the Russian Provinces of Archangel, Pskow Novgorod, *etc.*, and that various distillers exhibited samples of lichen spirits at the Russian Industrial Exhibition in Moscow, which were highly approved by the French and English visitors. The industry was a lucrative one in the northern provinces of Russia, yielding a net revenue of from 40 to 100%. Others (6) have reported on the carbohydrate composition of lichens on the Kola Peninsula, considered in connection with the problem of glucose production in northern localities. This includes a tabulation of carbohydrates present in eight lichen species, which shows them to be rich in polyhexoses, but poor in cellulose and in pentosan. Two small factories in Kirovsk have demonstrated the possibility of subjecting lichens to preliminary treatment with weak alkali solution in order to convert the bitter tasting lichen acids into soluble form. This is then hydrolyzed with dilute H_2SO_4, neutralized with chalk and purified with activated charcoal to produce a molasses containing 65 to 70% glucose. From this, crystallized (lump) glucose was obtained. The yield of molasses was 100%, based on dry lichen weight. However, molasses produced

by this process from lichens of the Cladonia group, especially *alpestris*, has a bitter taste, "the cause of which the authors are investigating".

Lichens vary in the amount of carbohydrates (lichenin) present. *Cetraria islandica* and *Cladonia rangiferina* have been found to yield up to 66% of polysaccharides which are readily hydrolized to glucose and then almost completely fermented to alcohol. Besides sugars capable of fermentation, lichen acids up to 11% of air-dried substance may be present. These acids as well as sodium

FIG. 9. *Parmelia saxatalis* on the lower side and *P. centrifuga* on the upper side of a rock. (*Photo by Auer, Finland*).

chloride have been found to retard the process. Experiments with *Cladonia rangiferina* have shown a total yield of 54.5% sugar which on fermentation produced 176–282 cc. of alcohol per kilo. Maximum returns of alcohol were obtained by steaming the lichens one hour under three atmospheres pressure, adding 2.5% of 25% HCl, resteaming for the same period of time and pressure, and finally neutralizing the product. Subsequent growth of yeast was normal, though fermentation could be accelerated by addition of H_3PO_4. An interesting modification of this procedure through addition of three parts by weight of H_2SO_4 and one part by weight of NCl at room temperature gave a pentanitrate similar to cellulose nitrate which, on gelatinizing with a solvent, produced a substance resembling horn (13).

Tanning. The tanning quality of lichens is due to an astringent property (depsides) peculiar to some species. *Cetraria islandica* and *Lobaria pulmonaria* were most used, and though not occurring in quantities sufficiently large to warrant industrial application, have been locally employed on a small scale.

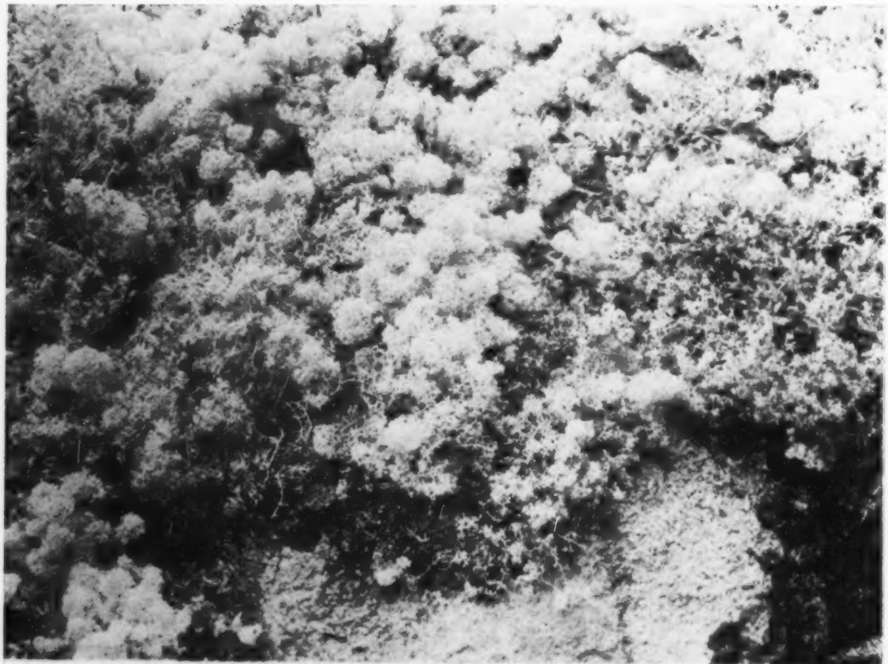
Dyeing. Synthetic dyes have largely replaced many formerly common vegetable dyes in the textile industry, primarily because of their low production cost and the fact that they generally surpass the natural products in fastness, particularly light fastness. Of the vegetable dyes, those obtained from lichens were renowned among the peasant dyers of old for their high quality and color, but today are the least known. Some of them are still popular in rural districts of Great Britain and the Western Islands, Iceland, Scandinavia, France and Germany. Interest in lichen dyes is being revived today somewhat in Scandinavia because of their use by the Hemslöjd (Home Industries Association), while there is some indication that the Irish Government is trying to reestablish this art in the poorer farming and fishing districts where these skills have been lost. That there is a good economic reason for such revival may be noted by the fact that the production of Harris Tweed cloth, dependent upon lichen dyes, is a carefully organized industry in Great Britain producing a luxury cloth of standard quality and great demand. The most attractive feature of home dyed and woven cloth is not only the dye utilized in its manufacture but also the individuality of the patterns evolved by a particular household or community. When these

are standardized, as they may be through government and association intervention, they lose much of their appeal to the retail trade. Under such controls prices tend to rise in excess of the true value, even for handicraft. It has been observed that wool dyed with lichen dyes is not attacked by cloth moths.

Mairet (13) states that none of the great French dyers used lichen dyes, nor are they mentioned in any of the old books on dyeing. Yet Amoreux, Hoffmann, and Willemet (13) published simultaneously in 1787, giving directions and samples with color names of lichen dyes as used by the French "tinctures" of their day, reflecting in part the universal application of these plants. Westring's (22) treatises on this subject, published from 1791 to 1806 in Sweden, are collectors' items, containing hand colored plates of the lichens and small water color panels illustrating the colors obtainable. These works established their author as an authority, and he is the source of information in later numerous, and often unacknowledged studies. Westring's system of the classification of lichen dyes distinguishes between lichen dyes which impart color to pure water (essential pigments) and those requiring certain treatment to yield color (preparable pigments). Lebail (13) in 1853 and Lindsay (11) in 1854, as well as others, classified lichen dyes according to the color produced, recognizing, however, that color varied with treatment.

History. Of all the lichen dyes used by man, none has attained greater historical and commercial importance than those of the Roccellaceae, variously known to the English as Orchella Moss, Orchella Weed, Orchil Paste or Orchil Liquor, to the French as Orseille, and to the Germans as Persis. Orchil and cudbear are preparations of lichens and not the actual plants. Lindsay (12) states that: "We may practically regard Orchil as the English, Cudbear as the Scottish, and Litmus as the Dutch name for one and the same (?) substance. The first being manufactured in the form of liquid of a beautiful reddish or purple colour; the second in the form of a powder of a lake or red colour; and the third in that of small parallelopipeds or cakes of a blue color. The commercial or trade designations of the dye-lichens depends upon the thallus being erect or pendulous, cylindrical or shrubby or flat, crustaceous, foliaceous, and closely adhering to the substrate. The former are "weeds" (*Roccella*); the latter are "mosses" (*Lecanora* and *Parmelia*)". The attempt to combine trade names and utilitarian characteristics with imperfectly known taxonomic features produced these peculiar groupings of widely different species.

Theophrastus and Pliny appeared to have been familiar with the dye of the Roccellaceae, while a Biblical reference has their origin in the "Isles of Elisha". During the Middle Ages the art of making this dye fell into disuse, and it disappeared from the markets of the world until the 17th and 18th Centuries when it again took on the aspects of an industry, and the "Weed" became an article of international exchange comparable to spices. Lindsay was particularly interested in the commercial aspects of lichens. His recommendations for a fuller investigation of the subject throws some light on the economic aspects of lichens in trade. He indicates that the field is comparatively new, and open to many possibilities, especially if the lichen resources of Scotland were exploited. "The speculation (investment?) of substituting home for foreign dye lichens promises to be remunerative as the roccellas have frequently reached the high price of £1,000 per ton in the London market". In 1855 he reemphasized that "if commanders of ships were aware of the value of these plants, which cover many



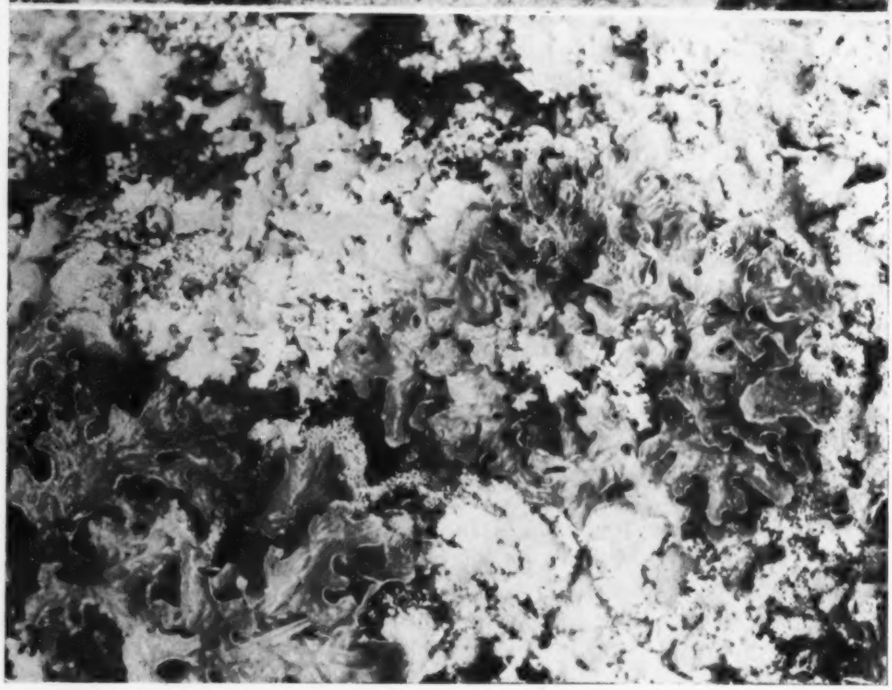


FIG. 10 (*Upper*). *Cladonia alpestris* (in clumps) and *Cl. rangiferina* (not in clumps) on Mt. Desert Island, Maine, U.S.A.

FIG. 11 (*Lower*). *Lobaria pulmonaria* growing with lighter colored forms of Parmeliaceae on a tree trunk. Mt. Desert Island, Maine, U.S.A.

a rocky coast and barren island, they might with a slight expenditure of time and labour bring home with them such a quantity of these insignificant plants as would realize considerable sums, to the direct advantage of themselves and the shipowners; and consequently to the advantage of the State". He even compromised the reforms of social revolution with the possibility of financial returns, saying that "indirectly, a multiplied trade in dye-lichens might scatter the seeds of civilization, and place the means of a comfortable subsistence at the command of the miserable inhabitants of many a barren island or coast, at present far removed from the great centres of social advancement . . .".

Blue and Red Dyes. About 1300 A.D. a Florentine merchant named Federigo (13) noted, while traveling in the Levant, that urine imparted a very fine color to some plants. On returning home he experimented, with success, and established the lucrative dye industry which founded the family name, Orcellarii, Ruccellarii or Rucellae, and gave to his native city a monopoly that persisted until the discovery of the Cape Verde Islands. This, though some think it derived from the Spanish term "Orcigilia", is thought to be the origin of the botanical term, Roccellaceae, which is descriptive of the group of lichens furnishing blue and red dyes. The first source of supply in the Levant and Mediterranean countries was controlled by the Rucellae and other merchants of Florence. Discovery of new lands broke this monopoly and revealed the abundance of the plants on rocks along warm sea coasts. The trading centers became, successively, Portugal, France and Holland. De Avellar Brotero (5) of Lisboa wrote in 1824, referring to the dye, that "its uses have been much extended for it serves as pigment to dye wool, silk, cotton, and various other fibers, it serves in paints, to color marble, wines, liqueurs, papers, pills, oil, grease, wax, *etc.*". New sources for the "weed" were found in the Cape Verde Island, Cape of Good Hope, Angola, East Africa, Mozambique, Madagascar, Zanzibar, Ceylon, the East Indies, Australia, Valparaiso (Chile), Lima (Peru) and the West Coast of North America. Shiploads of it were gathered from Lower California and adjacent islands.

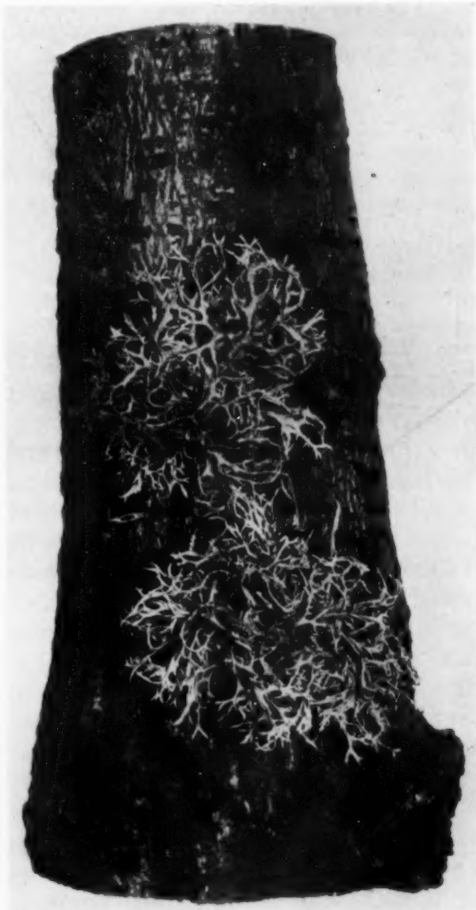


FIG. 12. *Evernia prunastri* on a tree trunk. (*Courtesy The New York Botanical Garden*).

The species which constitute the commercially valuable orseille lichens have been grouped as follows into orseilles of the earth (A) and orseilles of the sea (B), with the most important marked by an asterisk (16):

Dye Lichens and Their Sources

Locality	Type	Species
Pyrénées, Alps, Cévennes (France)	(A)	*Pertusaria dealbata* Cromb.
Auvergne (France)	(A)	*Lecanora parella* Ach.
Sweden	(A)	*Lecanora tartarea* (L.) Ach.
Norway	(A)	*Umbilicaria pustulata* (L.) Hoffm. and other *Umbilicaria* sp.
Canary Islands (Atlantic Ocean)	(B)	*Roccella tinctoria* Lam. & DC.
Madeira (Atlantic Ocean)	(B)	*Roccella tinctoria* Lam. & DC.
Mogador (North Africa?)	(B)	*Roccella tinctoria* Lam. & DC., *Ramalina scopulorum* Ach. and others.
Manila (Gorée) (Philippine Islands)	(B)	*Roccella portentosa* Mont.
Sardinia (Mediterranean)	(B)	*Roccella phycopsis* Ach., *Roccella tinctoria* Lam. & DC.
Angola (Africa)	(B)	*Roccella Montagnei* Bél.
Valparaiso (South America)	(B)	*Roccella portentosa* Mont.
Ténérife (Canary Islands)	(B)	*Roccella tinctoria* Lam. & DC.
Mozambique (East Africa)	*(B)	*Roccella Montagnei* Bél.
Madagascar (Indian Ocean)	*(B)	*Roccella Montagnei* Bél.
California (North America)	*(B)	*Dendrographa leucophaea* (Tuck.) Darb.
Cape Verde Islands (Atlantic Ocean)	*(B)	*Roccella tinctoria* Lam. & DC.

Importers of old were always reluctant to disclose the origin of their best supplies, but *R. tinctoria* of the Cape and South America were "6–8 inches long and as thick as goosequills" and so regarded highly by the dye merchants (40). In 1750 the Cape Verde and Canary Islands exported 100 tons annually to England. By 1818 the cost had jumped from 40 to £200 per ton, depending on the quality, but in 1886, with a stable supply from Ceylon where *R. tinctoria* grows abundantly on palms, the price settled at £50 per ton. Specimens of *R. fuciformis* DC. were exhibited at the London Crystal Palace in 1851, at which time the price quoted was £380 per ton. The latest figures available list the importation of tanning and dyestuffs into England for 1935 (13) as annatto, 837,919 pounds; Brazilwood, 854,581 pounds; lichen dyestuffs, 411,265 pounds.

The chemical nature of Roccella dye was not understood in early days, a lack of information that was further complicated by trade secrets and tradition. In the old English method the lichen was cut small or reduced to a powder by passing it through a sieve, and placed in iron drums provided with paddles. The mass was moistened slightly with stale urine, the mixture being stirred once a day with additions of soda for five or six days at a temperature of 35° to 45° C. Fermentation proceeded and was checked frequently until the coloring matter, a dove grey, ceased to increase. The product, Orchil Paste, was then placed in wooden casks and covered with lime water or gypsum solution until needed by the dyer. To make Orchil Liquor the lichen was treated with water and urine and permitted to ferment as for Orchil Paste, after which the fibrous matter was removed and the liquor collected and stored. Sal ammoniac and saltpetre were sometimes used in the process. Dillenius, 1741, "reckoned (the color) more beautiful when first dyed, than the Tyrian Blue", while Bancroft (13), in 1832, described the infusion of Orchil as of a red crimson inclining to violet.

Modern methods are based on more accurate knowledge of the chemistry of the lichen dye. According to Hill (13), the

lichen is sprayed with ammonia until the mass turns color, when the blue Orchil Liquor is extracted with water; if heated until the ammonia is driven off, red orchil results; afterwards the plants are dried and ground to a fine powder.

The French employed a crustaceous species commonly called "perelle" to obtain a purple-blue dye. M. Cocq, in the 81st volume of the Annales de Chimie, describes its preparation as observed at Clermont, France. The lichen was macerated in wooden troughs, six by three by two feet, and fitted with tight covers. Two hundred pounds of perelle and 240 pounds of urine were mixed in the trough and stirred every three hours for two successive days and nights, care being taken to keep the covers closed to avoid loss of the volatile alkali (ammonia). On the third day, ten pounds of sifted, slaked lime were added and well mixed with a quarter-pound of arsenic and an equal weight of alum. The mass was then stirred several times, once every quarter-hour, later every half-hour until fermentation was established, to prevent the formation of a crust on the surface of the mass. Fermentation was renewed by adding two pounds of sifted lime, and stirring once every hour for five days. On the eighth day it was stirred every six hours, and the processing might extend a fortnight to three weeks. The coloring matter was kept moist in closed casks until used. It was said to improve the first year, to suffer little change during the second year, and to begin to deteriorate in quality during the third year of storage.

Bancroft recommended the use of ammonia instead of urine, and of hogsheads to facilitate agitation; the addition of arsenic and alum he considered useless and dangerous. Use of human urine was commonplace, since it was the only early source of ammonia, and Lindsay (12) states that manufacturers recognized different qualities of it in producing the coloring matter: "Hence, I have been informed that some English manufacturers who continue to use this form of ammiacal solution, have learned by experience to avoid urine from beer-drinkers, which is excessive in quantity but frequently deficient in urea and solids, while it is abundant in water".

Brown and Yellow Dyes. Employment of brown and yellow dyes is an old custom in the northern countries of Europe. Fries remarked on the use of the class Lichenes, in the Arts "that almost all that is known has been owing to the Northern—the Anglo-Saxon, Scandinavian and German—Nations whom necessity constrained to value all of Nature's gifts". In certain districts of Scotland, as Aberdeenshire, almost every farm or cotter had its tank or barrel ("litpig") of putrid urine ("graith") wherein the mistress of the household macerated some lichens ("crotals" or "crottles") to prepare dyes for homespun stockings, nightcaps or other garments. The usual practice was to boil the lichen and woolen cloth together in water or in the urine-treated lichen mass until the desired color, usually brown, was obtained. This took several hours, or less on the addition of acetic acid, producing fast dyes without the benefit of a mordant or fixing agent. The color was intensified by adding salt or saltpetre. This method was prevalent in Iceland as well as in Scotland for those homespuns best known to the trade as "Harris Tweed".

Campbell, in the National Geographic Magazine, February, 1947, states that in the Hebrides "lichens from the rocks supplies a dye of misty brown, but the fishermen do not use this color while in their boats believing that what is taken from the rocks will return to the rocks". Horwood (13) reported that in the Shetlands the lichens were harvested in May or June or after rain in the autumn or winter, a metal scraper for rock species

FIG. 13 (*Upper*). Hemslöjd group near Uppsala, Sweden, with paraphernalia for dyeing with lichens collected in the immediate vicinity. The equipment consists of iron and copper pots heated over wood fires, chemicals and accessory dyes, and a small scale.

FIG. 14 (*Center*). Rinsing procedure, utilizing clean water of a stream. The white yarn is undyed and has been washed; the dark yarn has been dyed.

FIG. 15 (*Lower*). Drying the yarn after dyeing and washing (foreground). Undyed yarn hung up for convenience in handling (background).

being used. They were washed, dried in the sun and sometimes powdered, and were processed and shipped in casks to the London market as Cudbear. This term is derived from a corrupt pronunciation of the name of Dr. Cuthbert Gordon, chemist of Glasgow, who obtained a patent for his process of preparing the dye from *Ochrolechia tartarea* on a large scale. One person could collect 20 to 30 pounds daily, any one locality being visited every five years. After washing and drying, the collected weight was reduced to half.

Hooker (12) records that in 1807 at Fort Augustus a person could gain 14 shillings per week by collecting Cudbear, estimating a market price at three shillings, four pence per stone weight (22 pounds). Other observers have recorded it as an article of commerce about Taymouth, in Perthshire, in North Wales, Derbyshire, Westmoreland and Cumberland at one shilling one penny per pound in 1854, while the manufacturers of woolens and silks paid ten shillings a hundredweight for it with a profit of eight pence to the middleman. The manufacture of Curbear flourished about Leith and Glasgow because *Ochrolechia* (*Lecanora*) *tararea* from which it was prepared first came from the Western Highlands and islands around Scotland and was a chief source of revenue to the "poor Highlanders" whose other source of income, gathering sea-weed for potash salts, ceased. The value of this lichen to Scotland was said to have averaged £10 per ton, though other species, as *Parmelia perlata* Ach., sold at from £190 to £225 per ton in 1851. The manufacture of Cudbear moved into the hands of English Orchil makers who imported their materials from Norway and Sweden for the London market. From 1785 to 1788 24,000 kilo were shipped from Flekherjord, Norway (9).

For home use (see appendix) the cotters would mix the crotals treated with graith into a coarse paste rolled into

small balls or cakes with lime or burnt shells. These were wrapped in dock leaves and hung up to dry over peat fires, which accounts for the peat-smoke odor peculiar to homespun Harris Tweed cloth. In this fashion the dye would keep for a year or more; when needed, it was redissolved in warm water.

The colors of Cudbear and of Orchil are so similar as to be commercially indistinguishable. They dye best in a neutral bath producing a bluish-red or dull magenta shade but are frequently applied with sulfuric acid in conjunction with other vegetable dyes and coal tar dyes especially magenta. Addition of indigo and the dye of lungwort give a permanent black dye. *Roccella tinctoria* was used as the first dye for blue British broadcloth, having a purple tint against light. A variety of colors and shades can be obtained by the use of different species of lichens, varying the treatment with oil of vitriol, logwood or chemicals. Thus acids produce yellows, alkalies produce blues, lead acetate gives a crimson precipitate, calcium chloride a red precipitate, stannous chloride a red then yellow, while alum is more generally used by country folk for reds. The color of Cudbear is said to possess great beauty and lustre at first, but quickly fades and should never be employed unless for the purpose of giving body and lustre to blue dyes, as indigo ("bottoming"), or as a ground for madder reds (12). In deep shades the color has an intensity and body which cannot be equalled by coal-tar substances, and though they are not fast to light, milling or scouring, they do resist soaping but become bluer. Silks, and occasionally linens, have the dye applied in a soap solution with or without acetic acid.

Cudbear and Orchil have both been used in Holland for the manufacture of litmus, known to the French as "tournesol". After the dye is prepared, gypsum or powdered chalk is added and then cast into small, purplish-blue cubes, once sold as "lacunus". This, dissolved in water and soaked up in unsized paper, was retailed as litmus paper. This early product was rather unstable and tended to become colorless. The action is thought to be due to micro-organisms, so that alcohol or chloroform was often added when the litmus was stored in liquid form. Tincture of Cudbear was still used in the drug trade up to 1942 when the Dutch source of supply was no longer available and the U.S. Pharmacopeia recommended a coal-tar derivative, amaranth.

The chemical properties of dye lichens are better understood today because of the studies of the workers, previously listed. A comprehensive survey of lichen compounds may be found in Thorpe's Dictionary of Applied Chemistry, 4th ed., Vol. VII: 284.

Cosmetics and Perfumes

History. Since the 16th Century, or earlier, members of the families Cladoniaceae, Stictaceae, Parmeliaceae and Usneaceae have been utilized as raw materials in the perfume and cosmetic industries. At first this use consisted of drying and grinding the plants to a powder and combining them crudely with other substances, but as the manufacturers became more expert in their trade, these materials were skillfully combined into toilet powders, scented sachets and perfumes of real value. Three lichens commonly used were *Evernia prunastri*, *E. furfuracea* and *Lobaria pulmonaria* which have similar aromatic substances. The trades recognized these lichens under a variety of names, as "Lichen quercinus viridis", "Muscus arboreus, acaciae et odorante", "Eichenmoos" and more commonly as "Mousse de Chêne" or Oak-moss and Scented-moss. *Ramalina calcaris* Fr. was used in place of starch to whiten hair

of wigs and perukes. Cyprus Powder, a combination of *E. prunastri, Anaptychia ciliaris* and *Usnea* species, was scented with ambergris or musk, and oil of roses, jasmine or orange blossoms for use as a toilet powder in the 17th Century that would whiten, scent and cleanse the hair (19). After a somewhat lengthy eclipse, these plants reappeared as raw stuffs for perfumery, owing to the creation of scents with a deep tone and to the demands for the very stable perfumes of modern extraction, to which purposes they are almost universally applied to this day.

The principal species used in modern perfumes and cosmetics include *Evernia prunastri, E. furfuracea, E. mesomorpha, Ramalina fraxinea* Ach., *R. farinacea, R. pollinaria* Ach. and perhaps other species of the Ramalinae, though the last-named genus is not rated as so valuable as the former. *Lobaria pulmonaria* (Mousse de la base du Chêne) is used to some extent and is considered a more costly substance, perhaps because of its relative scarcity. Oak-moss (*E. prunastri*) of Europe is collected in shaded, damp habitats occurring in the central mountain ranges of Europe, the Piedmont of Italy and the forests of Czecho-Slovakia and Herzegovina. Not only the locality but the substratum is given a great deal of attention by the perfumer who differentiates between those plants that grow on oak (greenish) and those found on conifers (greyish); in the latter case rightly so, since resins may be included with the lichen, rendering it less desirable for the trade. In all instances the crop is gathered by peasants or shepherds, as in Jugoslavia, and pressed into large bales for export. The American supply before the war was derived from Jugoslavia, amounting to a few tons yearly at a cost of from five to seven and one-half cents per pound f.o.b., New York City. During the war a few companies, formerly established in France and Holland, became interested in developing the American market, but the lack of apt collectors willing to work for wages per pound equivalent to or slightly higher than those of the European gleaner rendered the commercial possibilities for the use of American plants somewhat doubtful. Experiments, including a number of North American species, have been carried out with little success, except with those traditionally used in the Old World. Of these there are sufficient quantities available in the northern forests of the United States and Canada to supply the domestic trade.

Chemical Properties of Essential Oil of Lichens. The use of dried, pulverized Oak-moss in the perfume industry is restricted, the principal sale being of extracts, essences and resinoids. Gildermeister and Hoffmann (13) state that the method of treatment involves exhausting the lichen by means of volatile substances and then removing the resins, waxes and chlorophyl with acetone. Addition of alcohol gives an "extract of Oak-moss" which may be used in this form or may be further concentrated in order to obtain a semi-fluid substance. French and German industrial research during the last 30 years has revealed much of the chemical nature of the extracts, gums and mucilages produced when processing lichens. Gattefossé (13) made a study of the essential oils and alcoholic extracts of all those lichens which were utilized as Oak-moss, obtaining data that caused him to conclude that oil of Oak-moss was almost exclusively a compound of phenol called "lichenol", an isomeric compound of carvacrol. These results were verified by St. Pfau (13) who further expressed the opinion that sparrassol, a metabolic product of the fungus *Sparassis ramosa*, is identical with methyl everninate resulting from the alcoholysis of everninic acid, present in proportions of about 2.8%, with a characteristic anise seed

odor. Walbaum and Rosenthal (13) repeated the experiments of Gattefossé and arrived at different results. They distilled the oil of *Evernia prunastri* and found that at ordinary temperature it formed an oily crystalline mass of dark color with a very powerful and agreeable odor. Further analysis revealed Gattefossé's error, and orcinol monomethylether, not lichenol ($C_{10}H_{14}O$), is the principal constituent of Oak-moss. This phenol, though not the main odoriferous part of the lichen oil, has a pleasant, creosol-like smell, and an ester, β-orcinol methyl carboxylate ($C_{10}H_{12}O_4$) which does not enter into the odor of the Oak-moss oil. In the resinous precipitate Walbaum and Rosenthal found ethyl everninate generated only during the extraction through esterification of the everninic acid ($C_{17}H_{16}O_7$) which was found to occur in a free state in the lichen; when boiled with baryta water it split into orcinol and everninic acid with the liberation of carbon dioxide. This acid is closely related to β-orcinol monomethylether and would be converted into it by the liberation of carbon dioxide. For these reasons Walbaum and Rosenthal felt that the genesis of the principal constituent of the odoriferous substances of Oak-moss had a close connection with the origin of everninic and evernic acids. Stoll and Schener (13) found in the volatile fraction some compounds which may also have a function in producing this odor, mainly thujone, naphthalene, borneol, camphor, civeole, citronellol, guaniol, vanillin, methylnonylketone and stearic aldehyde.

The multiplicity of types of essences and extracts may be due in part to the diversity of substrata on which these lichens grow as well as to the varying mixtures of species offered to the manufacturer in any lot, and the mode of extraction. This is also verified by the theory of multiple substances in lichens, as proposed by Burkholder and Evans (3). Hess (13) was able to extract atranorine and everninic acid from a specimen of *Evernia prunastri* growing on oak, but not from samples collected on beech or birch, while a sample from a lime-tree yielded some usnic acid. The whole problem is further complicated by the fact that most constituents of Oak-moss react upon the solvent. Treatment of lichen extracts with alcohol is seldom employed for preparation of essences, since it alters the evernic acid. Thus the lichenol obtained by Gattefossé, using this method was everninate of ethyl. The synthesis of everninic, divarine and other acids has been performed in the laboratory but has not been applied on a commercial scale. In the trade the oil is extracted by means of low boiling solvents, after which it is purified and decolorized, the process yielding 0.2 to 0.3 kilo of the raw extract or 20 to 30 gr. of the pure essential oil, depending on the technique of extraction in which 100 gr. of the dried lichen yield 8.5 gr. of crude everninic acid.

Uses of Essential Oils. The essential oil of Oak-moss or "concrete" is used in its natural condition in soap as an impalpable powder or in the form of a resinarome. The powder permits production of soap-balls agreeably scented at a reasonable price if the manufacturer can obtain a perfectly impalpable powder; otherwise they give the impression of containing sand. The soap manufacturer maintains the quality of his product by procuring his raw material from a reliable purveyor. To be sufficiently scented, soap balls should have 1 or 1½% by weight of lichen powder. When used for this purpose Oak-moss "concrete" improves, strengthens and cheapens lavender-scented products. It is essential in the higher grades of cosmetics in combination with other aromatic oils, *e.g.*, jasmine, tuberose and orange blossom. Iceland Moss, *Cetraria islandica*, has al-

ready been mentioned in connection with foods and medicine; in the field of cosmetics it serves as a source of glycerol in the soap industry and in the manufacture of cold creams because of its lack of odor. Some lichens, *e.g.*, *Sticta fuliginosa* Ach. and *S. sylvatica* Ach., have an objectionable fishy or methylamine smell.

The parfumeur recognizes abstract qualities in lichens which enhance his product. The peculiar reciprocity of the components forming the lichen unit and known to the unromantic biologist as "symbionts", are but an example of harmonious blending appreciated by the parfumeur. Therefore the extract of Oak-moss or Scented-moss "agrees" and "harmonizes" in the "happiest manner" with a large number of other essences. Its fragrance has been likened to musk-lavender, and as such it may be used as a fixative of the poppy type, blending well with bergamot, citron, acetate of lynalyl and linalol, thus supplying freshness; with neroli, jasmine, rose and cassia it improves the flavor of these flowers; it gives flexibility to tarragon, coriander, portugal, ylang-ylang and vanillin; contributes stability and depth to patchouli, vetyver, coumarin and musk, and "elevation" to alpha ionene. It also blends well with synthetic oils, *e.g.*, amyl and isobutyl salicylate and aceto-phenone. It is considered as an indispensable basis of numerous perfumes known to the trade as Chypre, Fern and Heath, and in many bouquets called "Fancy", as well as for the Oriental type of perfume. The absence of aromatic oils, glycerol or any other desired substance is no disadvantage for the use of lichens in cosmetics; *Cladonia rangiferina* and *Cl. sylvatica* have been recommended by parfumeurs, since they are whitish, easily dried and abundant "in open healthy places".

Miscellanea

Gums. The dyeing and paper industries have need for quantities of sizing with which to dress and stiffen silks, to print and stain calico, and to size paper. During the Napoleonic Wars, because of the French monopoly of Senegal Gum, Lord Dundonald attempted to introduce the use of lichen mucilage in place of the French product, but there is no evidence that the English market was interested. At Lyons the French appear to have successfully used lichen mucilage as a substitute for gum arabic in the fabrication of dyed materials (13). The problem has been investigated by Minford (13) who reports that Iceland Moss and some other lichens may be prepared as light-colored, transparent and high-grade gelatin, isinglass and similar gelatinous products, corresponding to those obtained from vegetable products for this purpose.

Lichens for Decorations. The use of lichens for home decorations, funeral wreaths and grave wreaths is commonly exploited in the northern countries of Europe, partly as a result of tradition and the expense of out-of-season flowers. The Cladoniaceae or Reindeer lichens lend themselves best to this purpose and are always used in center-piece table decorations in winter and in connection with Christmas ornaments. In older types of Swedish houses, where the outer or storm window can be separated from the permanent window, the space between at the base is filled with this lichen which may act partly as insulation. Dry lichens are brittle and are usually gathered and worked in the fall of the year when the air is moist; they are woven into wreaths by the poorer farming class who offer them for sale on market days at low prices. Addition of water, as for cut-flowers, does not preserve them but tends to make them moldy. Lichens can maintain themselves on hygroscopic water. The harvesting of lichens, especially *Cl. alpestris*, can be a source of considerable revenue. In 1935, 2,900 boxes (orange

crate size) were exported from Norway. In 1936, 7,700 boxes were shipped, and in 1937, 12,500 boxes which yielded a revenue of 90,000 Norwegian Kroner ($1.00 = 4.90 Noar. Kr., Aug. 1947). Later shipments went only to Germany, and the Göteborgs Handels-Och Sjöfarts-Tidning (newspaper) published a story on October 12, 1946, entitled "Fjällresa Med Linné", which said that this lichen export was being used by the Germans as a source for "explosives". The Germans had an essential need for this plant also as grave decorations. The gathering of these lichens for decorations is cause for further dispute between Lapp herders and commercial harvesters. *Cladonia* species are occasionally used in table models and dioramas to represent trees.

Injury by Lichens. Lichen injury to valued stained glass windows of old cathedrals and to marble, alabaster and Florentine mosaics has been reported by various observers (13). Orchardists and silviculturists have long been interested in the relationship of lichens to trees, and many sprays, including Bordeaux mixture, caustic soda and light-boiling tar oils, have been recommended for the removal of these "unsightly if not injurious plants". Indirectly they may be the cause of economic loss by serving as shelter for harmful insects seeking cover and depositing eggs. Kaufert has noted that the bark of *Populus tremuloides* remains permanently smooth through the presence of a persistent periderm, but that if injured by fungi, lichens or mechanical injury the bark may be stimulated to develop rough fissures. In studying the influence of *Usnea* species upon trees in South Africa, Phillips (13) concluded that in this case the lichen is definitely detrimental in that its fungal component is parasitic upon tissue external or internal to the cork cambium. Vigorous crowns as well as defective ones may be infected. Since the lichen cannot develop luxuriantly under the conditions obtaining in undisturbed high forests, he recommended that the forest canopy be preserved as a means of inhibiting the rampant growth of this lichen. Wellborn (13) suggested that some leaf spots of the coffee plant may be caused by a lichen, and the classical research of Ward (21) on *Strigula complanata* Mont. illustrates the undeniable harmful effect of a lichen ephiphyte on a crop plant. Leaf lichens are common on evergreen, deciduous trees and bushes in the subtropics and tropics, but unless the leaves of such phanerogams have a commercial application, as tea leaves, there is no economic loss involved. Foresters in some parts of Europe recommend scraping lichens from trees, but there is little experimental proof that lichens ephiphytically attached to the bark, branches and twigs of trees are the cause of damage. Howbeit, the whole problem of whether lichens injure the trees on which they are fastened cannot be solved, as Elias Fries once remarked, "by mere denial".

Dyeing Instructions for Home Use (10)

Parmelia saxatilis. The Swedish country people call this the "Dye-lichen" or "Stone-moss". It occurs abundantly on rocks and stones as rugose greybrown patches, and should be collected after rain while the air is still moist, for it is firmly attached to the stones and will crumble if removed in dry air. It is most easily separated from the stones by an ordinary table knife, and if it is to be preserved it must be carefully dried before being packed in bags or boxes. Before use it should be finely crushed. The following colors may be obtained by varying the dyeing treatment.

1) Light yellow-brown. Place one kilogram (2.2 pounds) of finely crumbled Dye-lichen in a copper kettle containing a large quantity of water. Place 250

grams* of unmordanted (raw) yarn into this solution, boiling and stirring the yarn for one-half to two hours, depending on the desired shade of color. The best method of stirring the yarn is to wind it around sticks so as to avoid cloudy or uneven dyeing. When the process is completed, the yarn should be washed thoroughly in several changes of clean water, after which it may be hung up to dry, making sure that the skein hangs freely.

2) Dark brown. The lichen is crumbled and placed in layers with wool or yarn in an iron kettle. The yarn should be wet when put down, and after addition of cool water in sufficient quantities to cover the mass, several hours should lapse before boiling. Boiling must be slow and regular with constant stirring for two to six hours. If a very dark color is desired, the yarn may be boiled again in a fresh quantity of the Dye-lichen. If the desired color is black-brown, some braziline (Brazilwood chips) should be added. If dark brown color tones are desired, best work with grey yarn. Wash as above.

3) Rusty brown.

250 grams of yarn
40 grams of alum
15 grams of tartar
2 kilograms of lichen

The yarn is mordanted in alum and a solution of tartar one-half to one hour. The lichen is boiled in a large quantity of water for one hour, after which the mordanted yarn is added and then boiled for two hours. The best method is to have the hanks strung on sticks. If the yarn is not turned over maculation will result. If a red tone is desired, the yarn should be removed from the kettle and boiled one-half hour in a solution of 30 grams of soaked madder. Wash as above.

4) Dull Brown. Use four times as much crumbled lichen as yarn by weight and soak in water one day before boiling. Then boil for one hour. Add a solution of soap to the unmordanted yarn and boil another two hours, then permit it to cool. Remove the yarn and wash as above.

Cetraria islandica. This lichen, commonly known as "Iceland Moss", grows abundantly in woods and in the mountains. It is loosely attached to the ground, and is best collected in dry weather so as to save the trouble of artificial drying before storage for winter use. Before using place it in fresh water for softening, after which it is easy to chop up. Like the Dye-lichen, it gives beautiful brown colors but in different shades, and has been found to be of value in dyeing suede, since it produces the faint pastel tints desired by the trade (19*a*).

1) Brown. The lichen is cleansed, washed and finely crumbled before being placed in a kettle, alternating layers of wool or yarn with lichen. Water is added and all is boiled half an hour. Iron vitriol should be dissolved in warm water and carefully added to the mass. This is boiled slowly, stirring constantly until it is sufficiently dark. Wash as above.

Usnea barbata. This is the Beard-lichen and occurs abundantly in woods, growing on both coniferous and foliaceous trees and wooden fences, hanging down as a light grey beard. The lichen is branched, soft and elastic, and when it is pulled out the outer crust bursts and a white horsehair-shaped inner thread is left. When collecting, this lichen should be separated from needles and twigs. It gives a fine red-yellow color.

1) Red-yellow.

250 grams of yarn
32 grams of alum
250 grams of Beard-lichen

The yarn is, as usual, mordanted with alum. Boil the Beard-lichen one hour and strain off, adding the yarn to the solution and boiling for one-half to one hour, depending upon the desired shade of color. Lighter shades are obtained by using weaker solutions.

Alectoria jubata. The color of the Horsehair-lichen is greybrown or black. It grows commonly on old coniferous trees, hanging down from the twigs in long tufts. Its branches, when pulled, do not behave as do those of the Beard-lichens, but, like that lichen, it gives a yellow-brown dye, though of a different tone.

1). Yellow. Follow the instructions as for the Beard-lichen. The darkest shade will be mellow green-yellow. By diluting the solution lighter tones of a fine cream-yellow may be obtained. Wash as above.

Notice! For obtaining lighter shades of colors the yarn must be boiled six times in weaker solutions. It is not advisable to use stronger solutions for shorter times. This rule can be generally applied in all cases.

Acknowledgments

The author is greatly indebted to Dr. G. Einar Du Rietz, Director of the Plant Science Institute, Uppsala, Sweden, for the many courtesies received as a student at that Institute; to Dr. Gunnar Degelius for advice and the generous loan of his valuable collection of books and duplicates; to Dr. Rolf Santesson of the Institute for Systematic Botany for his assistance; to Dr. Magnus Fries for the use of the Th. M. Fries Lichenological Collection; to Dr. A. H. Magnusson for the use of his library; and to the Librarian of the Carolina Rediviva, Uppsala University, for many favors. The author expresses his appreciation also to the American-Scandinavian Foundation, New York City, for the Fellowship which made it possible for him to study at the Royal University of Uppsala, Sweden from 1946–1947; and to Dr. C. W. Dodge, Missouri Botanical Garden, for his kindness in checking the final manuscript of this article.

The author is greatly indebted also to Miss Carlsson of the Uppsala Hemslöjd Association for her kindness in demonstrating the dyeing technique followed in her classes and in exhibiting materials dyed with lichen dyes. Her advice and suggestions have been incorporated in this paper. Dr. Sten Ahlner, Växtbiologista Institutionen, Uppsala, translated "Dye Instructions" for the author who acknowledges his assistance in this and many other instances.

* 1 ounce = 28.35 grams; 1 pound = .45 kilograms.

Literature Cited

1. Barry, V. C. Nature **158**: 863–865. 1946.
1a. ——— and P. A. McNally. Nature **156**: 48. 1945.
2. Burkholder, P. Proc. Nat. Acad. Sci. **30**: 250–255. 1944.
3. ——— and A. W. Evans. Bull. Torrey Bot. Club **72**: 157–164. 1945.
4. Dannfelt, H. J. Kungl. Lantbrukssakad. Tidsk. **6**: 483–498. 1917.
5. de Avellar Brotero, Felix. Historia natural da orzella. 16 pp. 1824.
6. D'yachkov, D. and A. Kursanov. Doklady Akad. Nauk. S.S.S.R. **46**: 71–73. 1945.
7. Feé, A. L. A. Essai sur les cryptogames des écorces exotiques officinales. 167 pp. 1824.
8. Florovskaya, E. F. Bot. Zeitg. **24**: 302–313. 1939.
9. Høeg, O. A. Lav og Mose som Nyttevekster. Suppl., 125–147. 1938.
10. Larsson, Beda. Hemfärgning med växtämnen rad och anvisningar. 1946.
11. Lindsay, W. L. Edinb. New Phil. Jour. p. 40. 1854.
12. ———. Edinb. New Phil. Jour. p. 26. 1855.
13. Llano, G. A. Bot. Rev. **10**: 1–65. 1944.
14. Quispel, A. Rec. Trav. Bot. Néerl. **40**: 413–541. 1943–1945.
15. Raistrick, H. Ann. Rev. Biochem. **9**: 571–592. 1940.
16. Ronceray, Paul-Louis. Thèse. École Supérieure de Pharmacie, Univ. Paris, #10. 94 pp. 1904.
17. Sastry, V. V. K. Indian Acad. Sci., A., Proc. **16**: 137–140. 1942.
18. Santesson, C. G. Arkiv Bot. **29** A;2, No. 14. 6 pp. 1939.
19. Smith, A. L. Lichens. 404 pp. 1921.
19a. ———. Recent lichen literature. Trans. Brit. Myc. Soc. **15**: 193–235. 1931.
20. Stenberg, S. Om tillverkning af läfbränvin. 52 pp. 1868.
21. Ward, H. M. Linn. Soc. London, Trans., Bot. **26**: 87–119. pl. 18–21. 1884.
22. Westring, J. P. Svenska läfvarnas färghistoria, *etc.* 1805.

Tagua or Vegetable Ivory–*A Forest Product of Ecuador*

Tagua is the hard seed of a South American palm tree, highly valued for manufacture into buttons and other small articles requiring a hard, easily cut, lustrous material.

M. ACOSTA-SOLIS
Director, Ecuadorian Institute of Natural Sciences

Introduction

In the tropical and humid mountains of Ecuador there grows a beautiful palm, the tagua, which produces the "marfil vegetal", or vegetable ivory, of commerce. It is known in Ecuador by several common names, according to the different regions of the country, *viz.*, "cade" or "cadi", "coroso", "mococha", "cabeza de negro", *etc.* This palm plays a very important role in the life of the "montuvio", as the inhibitant of the forest is known, and in that of the farmer; and before the second World War it was significant in the affairs of the merchant and in the economic balance of Ecuador as a whole. The tagua "nut", as the seed is sometimes known, ranks commercially with cinchona, rubber, balsa, kapok, copra, sarsaparilla, fine woods and barbasco fish poison as an economically important forest product of the country. For the "montuvio" of the coast tagua always means money, a roof and food; for the farmer, money and shelter; and for the merchant and the State, profit and revenue.

Tagua grows in abundance in the five provinces of the Ecuadorian coast: Esmeraldas, Manabi, Guayas, Los Rios and El Oro. All these provinces have commercialized the hard, compact, heavy, brilliant seeds, so highly valued for their thousand uses and industrial applications, especially in the button industry. Up to a few years ago the first of these provinces lived primarily by exploitation and export of the seeds, and a great part of their economy revolved around the commercial movement of tagua. In the western part of the country the inhabitants also rely greatly on this palm, either as a source of the commercially valuable tagua or as a source of timber and foliage for house construction and roofing purposes.

Commercial tagua, coroso or vegetable ivory, as the product is also known, is the hard endosperm of the seed of the genus *Phytelephas*, typical of the damp, tropical climes of Ecuador and Colombia. The material is white, ivory-like, hard, heavy, smooth and opaque, odorless and tasteless, and acquires a brilliance with polishing, but is not elastic or durable as is genuine ivory. Buttons, toys figurines and other objects made of it lose their hardness when placed in water for some time but recover this quality when dried and exposed to the air; genuine ivory does not soften in water.

In spite of tagua thus being a very important species in the national economy of Ecuador, relatively little has been published, either botanically or agriculturally, to make it known. It is for this reason as well as to meet the requests of colleagues in the United States, Brazil and Argentina that the author has prepared this resumé on

the subject, based upon both his own travels in Ecuador and other sources of information.

Ecuadorian Species

The general name "tagua" is given to seeds and to the trees themselves of the genus *Phytelephas,* within which four specific names have been applied:

Scientific name	Region in which it grows
Phytelephas aequatorialis Rich. Spr.	Outer western slopes of the Cordillera and the forests of the coast.
P. macrocarpa R. et Pav. = *Elephanturia macrocarpa* Willd.	Western and eastern sections, from sea level to 1,800 meters.
P. microcarpa R. et Pav. = *Ph. ·elephas* R. et Pav. = *Palmae phytelephanteae* Krst.	Outer slopes of the two Cordilleras, preferring damp places.

P. aequatorialis and *P. macrocarpa* are very similar, and these names, therefore, appear to be synonymous. The habitat, development, morphology and even the fruit of the two trees are almost identical, and in both cases the stems are tall and well developed when old. *P. microcarpa* is different in having almost no stem, male perigynous flowers with pluridentate edges, and smaller fruits.

Common Names

CADE—This name is given to the whole plant in the mountains of Santo Domingo de los Colorados, Quininde, and on the outer slopes of the western cordillera towards Esmeraldas, Manabi, Los Rios and Guayas.

CADI—In the mountains of Bucay, Guayllanac and Naranjal this name is applied to the plant, and its product is called "cadi" seeds.

CABEZA DE NEGRO (negro head) —Usually given to the fruit in the north of Esmeraldas Province and in Colombia.

COROSO—Given to the palm, and especially the seeds, in Limones, Balzapamba and Babahoyo, Los Rios Province.

MAZORCA—Given to the fruit in Esmeraldas and Manabi Provinces and in the western valleys of Bolivar Province.

MOCOCHA—Given to the palm and fruit in Bucay, Balao, Jesus María and other sections of el Guayas Province.

YARINA—Given to the palm and fruit in the eastern region.

TAGUA MACHO (male tagua)—Given to the staminate tree. It should be noted that tagua is a dioecious palm.

TAGUA HEMBRA (female tagua)—Given to the pistillate tree which produces the fruits, or "cabezas" (heads) or "mocochas", as they are also known. It is of course only the pistillate, or female palm, which, after being pollinated from the male palm, bears the fruits.

Habitat and Distribution

Tagua grows in Ecuador by preference in the damp mountains of the coastal and eastern regions, and on the outer, lower slopes of the western and eastern Cordilleras. *P. macrocarpa* extends from sea level in Esmeraldas to 1800 meters above sea level along the Quito-Santo Domingo de los Colorados Highway, but is more abundant from 400 or 600 meters to 1,500 meters. Following the Guayaquil-Quito railroad, the author has seen it from Barraganetal to a little above Naranjapata, and into the interior of these mountains, 120 to 1,100 meters altitude. It is also abundant and almost always on the outer slopes of the western Cordillera, in the Bucay and Guayllanag sections, from 350 to 1,400 meters, especially from 1,000 to 1,200 meters above sea level. It is called "cadi" in these regions. Large quantities are to be seen in the descending valleys of the western Cordillera in Bolivar Province—Telimbela, Tablas, Limon, *etc.*—where it is used mainly for its durable leaves in

thatching houses, for which it is the preferred material. There are also many rich "manchas" (patches) of tagua in the western sections of Azuay and Cañar Provinces, but it is less exploited there than in the other provinces.

The tremendous quantity of tagua in Esmeraldas Province accounts for the apparent inexhaustability of the "taguales" (stands of tagua palms) and for the source of wealth that they constituted in former times for the Esmeraldian negro and merchant, particularly before the last war. The taguales of Esmeraldas Province grow and flourish best along the rivers in the fluvial valleys and in the really humid forests, in contrast to what has been observed on the mountains in western Sibambe and Guayllanag, and in the western part of Bolivar Province, which has a dry season of six to seven months duration. The basins of the Esmeraldas, Rioverde, Ostiones, Santiago, Cayapas, Bogota and other rivers are rich in taguales, and in rubber and balsa as well.

South of Esmeraldas Province, in the Muisne section, there are so many taguales that it seems that they will never be exhausted, and these formations extend abundantly throughout the Province of Manabi. There are also groupings of tagua on the outer slopes of the eastern Cordillera, but in smaller quantity than those observed on the western slopes.

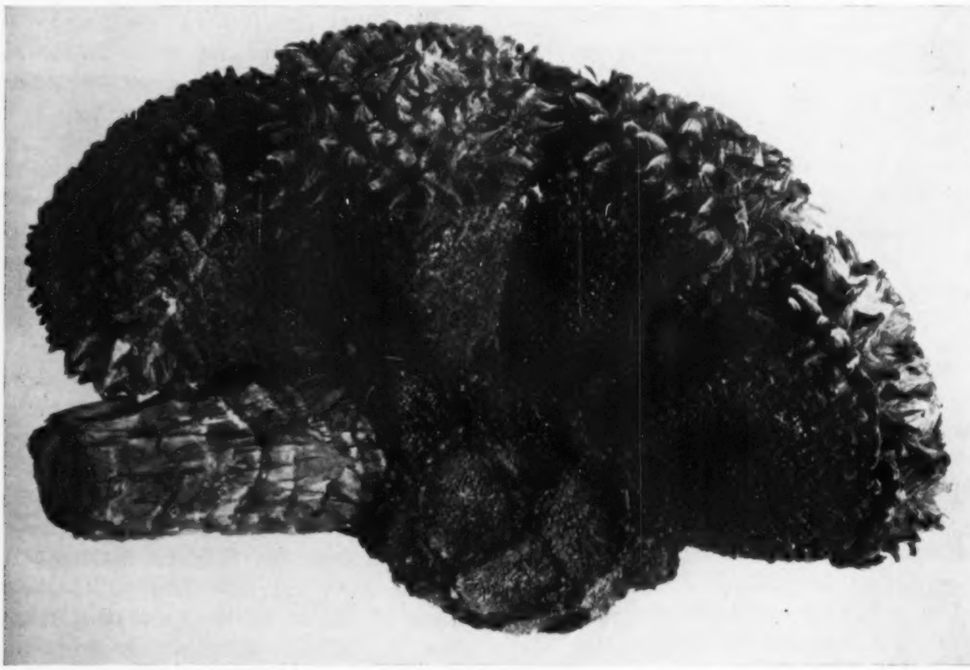


FIG. 1. A fruiting cluster of tagua, composed of several woody and spiny carpels, each of which contains four to six seeds. Some of the carpels of this "cabeza" have been removed to show their points of attachment. "Cabezas" may weigh as much as 40 pounds. (*Courtesy U. S. Dept. Agr., Off. For. Agr. Rel.*).

According to his own observations, the author believes that *P. microcarpa* grows better in low, damp places, or in the forests better protected from light, as was noted on his trip from Santo Domingo de los Colorados to Quininde; that is to say, its habitat is similar to that of the same species growing in the fluvial valley of the Magdalena in Colombia.

Although tagua grows in all of the tropical lands indicated, it prefers naturally drained or porous soil. The clayey-stony terrain of the Province of Bolivar is ideal, as is also the clayey alluvial terrain of the Santiago River basin in Esmeraldas Province.

The best temperature for development of tagua on the Esmeraldas coast was recorded by the author at 27.1° C during four and a half months of observation (May 15 to September 30, 1940) in the "summer" season or months of drought. The average given was obtained from six daily observations, at 6, 9, 12, 13, 18 and 21 o'clock. More climatic details on this province are given in his book entitled "New Contributions to a Knowledge of Esmeraldas Province".

To give a general idea of the environment in which the tagua grows splendidly, the following thermal and humidity data obtained by the author in many places where this palm grows abundantly, give a general idea of the optimum environmental conditions for its best development:

and to produce fruit, the bases of the leaves are still in the earth, giving the appearance that the fruit emerges from the ground like a giant tuber. At 14 or 15 years the female palm begins to produce fruit and continues to do so uninterruptedly every subsequent year. A tagual (tagua palm) lasts many years, and even centuries in the mountains, but its longitudinal growth is very slow. A tagual with a stem two meters tall, for example, can be not less than 35 to 40 years of age; isolated examples with stems five to six, and sometimes eight to ten meters tall, not counting the leafy crown, may be at least a century in age.

The fruit, known in Ecuador as "baya", "cabeza" and "mazorca", is generally spherical in shape and 12 to 36 cm. in diameter. When mature it consists of a number of clustered, woody, coarsely spiny carpels, each of which contains four to six seeds. The entire mazorca is dark brown or black, and its resemblance, from a distance, to a negro's head accounts for its local name of "cabeza de negro".

WESTERN MOUNTAINS OF SIBAMBE

Area	Alt. in meters	D.T.	H.T.	D.Ob.	Date
Bucay Section	345	23.30	20.5	2	11–12 Aug., 1943
Guayllanac Section	1350	19.0	17.5	1	13 Aug., 1943
H. La Carmela	1110	21.5	18.3	4	15–18 Aug., 1943

WESTERN MOUNTAINS OF BOLIVAR

Area	Alt. in meters	D.T.	H.T.	R.H.%	V.T.	D.Ob.	Date
Telimbela	1180	19.3	18	95	15	3	21–23 Nov., 1943
Tablas	1060	22	20.3	94	17	4	3–6 Oct., 1943
Limon	1200	19.8	19.5	90	15.6	9	15–23 Oct., 1943

KEY: Alt.—altitude; D.T.—dry temperature centigrade; H.T.—humid temperature centigrade; R.H.%—relative humidity %; V.T.—vapor tension; D.Ob.—days observed.

Vegetative Development and Production

Tagua attains complete development after ten years, more or less; that is to say, growth is not so slow as is commonly believed, in comparison with that of similar palms. But even at 14 or 15 years, the age at which it begins to flower

Well developed palms produce 15 or 16 mazorcas annually, each of which weighs eight to 15 kilograms [kilogram = 2.2 lbs.], but an average weight between these two extremes is more commonly found. However, they often reach up to 19 kilograms. It is noted generally in practice that a quintal [= 100 pounds] of

seeds with their shells is obtained from 12 cabezas; this weight is at times also obtainable from only eight well developed cabezas, and even from only four. A quintal of unshelled tagua yields approximately 60 pounds of shelled tagua seeds. The seeds are about the size and shape of hens' eggs and generally weigh one to three and a half ounces each; it has not been rare, however, to find in some fruits of Esmeraldian tagua, seeds weighing up to eight ounces. On the basis of size and weight, three qualities of seeds are known in commerce: large

FIG. 2. Tagua seeds, or vegetable ivory "nuts", each of which is about the size of a hen's egg. (*Courtesy U. S. Dept. Agr., Off. For. Agr. Rel.*).

tagua, 100 seeds of which weigh 240 ounces; common or medium tagua, 100 seeds of which weigh 208 ounces; and small tagua, 100 seeds of which weigh only 160 ounces. The first quality is preferred in export for the manufacture of large buttons. Since tagua palms produce uninterruptedly all year and every year, after the twelfth or fifteenth year of life, the production of seeds is enormous.

Exploitation and Rudimentary Cultivation of Tagua in Esmeraldas Province

With the exception of the few cultivated taguales that I have seen in the Santiago River basin, Esmeraldas Province, over and above the extensive sylvan taguales, tagua is not cultivated in Ecuador, in spite of the commercial importance it has represented for the national economic balance.

When the commercial price for tagua has been good—ten or more sucres per quintal—[sucre = 7¢], the "montuvio" or the negro either has been content with going into the mountains and collecting the seeds without injuring the trees, or has resorted to the destructive "maceado" system. He then sells them in the principal commercial centers to either wholesalers or export agents of Borbon, Limones, Rioverde and Esmeraldas in Esmeraldas Province; of Bahia, Manta and Portoviejo in Manabi Province; of Babahoyo in Los Rios Province; of Guayaquil in Guayas Province, *etc*. The products collected in the coastal provinces are exported from Esmeraldas, Bahia, Manta, Guayaquil and Puerto Bolivar.

In Esmeraldas Province transportation of tagua from the forests is performed almost exclusively on large rafts which follow the course of the river. In the Provinces of Manabi and El Oro, which are the heaviest producers, transportation is by mule-back.

Harvesting is carried on throughout the year, as the plant, once it arrives at maturity, flowers and bears uninterruptedly all its life. The quantity of the product harvested depends solely on the price paid; when the price is good, harvesting is extensive.

For a long time tagua has constituted a natural and freely exploitable wealth for the "montuvio" and negro. Their method of harvesting is primitive and

usually destructive, especially when they use the "maceado" or striking method, which involves cutting the fruit, or "mazoreas", while still tender, before maturation. Even worse, when there are fruits high in the palms, the negro, in his eagerness to harvest more, will fell the entire tree. This method kills the plant, for the tree does not sprout from the base. The young fruits thus collected are submitted to artificial maturation by being buried under leaves, garbage, *etc.* After ripening, the seeds are removed by mallet blows, whence the name "maceado" for this method of harvesting, or better, destroying the tagua of the forests. The seed obtained from young fruit of forced maturity has a light coffee or blond color and is known as "blond tagua" to differentiate it from "black tagua", the seed from fruit naturally ripened on the palm. "Blond tagua" and "black tagua" are generally sold or exported "skinned", that is, with the "shell" or perisperm removed.

Whenever the commercial price of tagua has been good, the negroes have had a lot of business, making a lot of money and completely forgetting their other labors, especially agriculture. In the midst of this indolence towards agriculture in general and toward tagua in particular, not only in Esmeraldas Province but in the whole country, it has been very encouraging to the author to note that the inhabitants of the Santiago River basin in Esmeraldas Province have become interested in the cultivation of this very important palm, in spite of the great natural resources which exist in the taguales of the forest.

On the flat lowlands and river banks in the north of Esmeraldas Province, principally in the basin of the Santiago River, the taguales form groupings unmistakeable because of their dark green color, at the same time beautifying the landscape. Tagua has been cultivated only 40 or 50 years in the Santiago River basin. It appears that when Dr. Theodore Wolf traversed the region in 1877 this valuable species was not yet under cultivation, for he makes no mention of it in his "Memoirs". The plantings that I have seen in the basin of the Santiago River are irregular, the distance between trees varying from two to five and more meters. In setting out an "orchard", the mountaineers do not first prepare seed beds but merely scatter the seeds, and when the seeds have sprouted and have developed somewhat, the mountaineers remove the weeds and regard the tagual as being established. Sometimes they thin out the plants that have sprouted too closely, and sometimes they do not, but in either event they wait for the trees to produce, which usually happens 15 years after planting.

Introduction of improved methods in the cultivation and exploitation of tagua is very desirable in order to obtain a more profitable yield. Although tagua has not amounted to much during the war years, one can be sure that very soon it will again acquire the old demand. Without doubt there will be new uses for it in accordance with industrial advances.

Insects and Diseases

In the mountains of Bucay, Guayllanac and Esmeraldas the larvae of a coleopterous insect attack the stems of tagua, destroying the pith with voracity until the trees are killed. The identity of this destructive insect is unknown to the author, but the larvae and adult of it are very similar to those of another known as "gualpa" (*Rychophorus palmarum* L.) in Esmeraldas Province which attacks the pith of coconut trees.

Another coleopterous insect, a species of *Dryocoetes*, which attacks only the fruit of tagua is distributed from El Oro and Guayas to Esmeraldas Province. The author's acquaintance with diseases of tagua is limited to the observations that the seeds in many fruits do not ripen and that the leaves sometimes wither before attaining normal size. Could these

maladies be caused by fungi, by viruses or by bacteria? To determine what is the cause and possible control would be of value.

Production and Markets

Before the recent World War Ecuador occupied an outstanding position in the export of shelled tagua, large quantities of this product being sent to Europe and the United States. Tagua from the mountains of Esmeraldas has had great prestige for its unsurpassable quality, and, according to Dr. T. Wolf, the tagua from Atacames, Rioverde, Esmeraldas and the whole basin of the Santiago River to the border of Colombia, is the best in the world.

Before the first World War Germany absorbed the greater part of the export of tagua from Ecuador, and justly so, since it was the country in which the first experiments regarding utilization of tagua were made. On the return trip to Hamburg on one occasion a German ship found it necessary to take as ballast several tons of tagua obtained in Ecuador. This was the first time the product was introduced into Germany, and it naturally attracted the curiosity of the investigating and practical spirit of the German people who immediately found a use for it as a substitute for ivory and shell in the manufacture of buttons and small articles of adornment. This seems to have happened about 1865. Thus it was that the export of Ecuadorian and then Colombian tagua was started, not only to Germany but to other countries, including the U.S. Since the first World War, however, Germany has occupied second or third place in the importation of tagua, as can be seen in the following statistics. Between the two World Wars the United States has occupied first place as the importer.

Statistics of either tagua exports from Guayaquil or of production for the country as a whole have not been available. Only the following have been obtainable:

EXPORTS OF SHELLED TAGUA THROUGH THE PORT OF ESMERALDAS

Year	Weight in kilos	Value in sucres
1928	2,563,806.84	491,238.94
1929	4,369,674.94	910,115.05
1930	2,137,207.50	341,456.92
1931	1,981,952.00	241,398.30
1932	1,271,742.55	109,833.77
1933	2,721,243.15	310,265.30
1934	4,263,883.38	891,078.11
1935	3,200,223.40	629,837.64
1936	3,933,643.50	115,384.73
1937	2,954,512.58	1,568,876.15
1938	1,719,099.72	640,085.50
1939	1,377,921.00	461,671.65
1940	1,084,289.00	342,985.47
1941	1,081,771.00	322,401.39
1942	347,070.00	701,526.08
1943	397,610.00	533,421.92
1944*	32,733.00	12,098.51

* Only the first third of the year.

From the first table on page 53 it can be seen that for the years given the United States occupied second place in tagua imports from Ecuador in spite of the fact that it imported tagua also from Colombia, Panama, Peru and Brazil. In 1928 Ecuador supplied 53% of its tagua imports, a percentage which rose to 67.85% in 1929, to 76% in 1930, and to the high figure of 92.62% in 1931, as can be seen from the second table on page 53.

There are two classes of commercial tagua in export industry—"select black" and "select blond". Both kinds are exported without their horny shells. Blond tagua is preferred abroad in the button industry because of its ease of cutting, but in no way does the price compensate for the great destruction in the forests involved in obtaining it. Export of it is prohibited, and only black tagua enters into commerce. The price of tagua in the New York market, as in any other port, depends completely on its quality, be it with or without shell, round or elliptical, small or large. Ecuadorian tagua had in 1931, for example, the following prices in the port of New York: tagua from Esmeraldas, with shell, from $1.75 to $2 per quintal; tagua from Manta, shelled, from $2 to $2.50 per quintal.

TOTAL EXPORTS OF ECUADORIAN TAGUA[1]

Destination	1929 Number of kilos	1929 Value in dollars	1930 Number of kilos	1930 Value in dollars	1931 Number of kilos	1931 Value in dollars
Italy	9,299,483	430,543	8,708,065	317,049	....	....
U.S.	8,209,392	374,504	4,552,434	162,611	....	....
Germany	3,849,614	198,676	2,528,000	97,010	....	....
France	2,495,116	120,645	2,613,984	90,122	....	....
Spain	1,099,937	55,095	1,045,280	36,035	....	....
England	397,675	25,184	80,900	22,145	....	....
Other countries	440,606	10,607	488,205	4,654	....	....
Totals	25,791,823	1,215,254	19,986,868	729,626	19,366,030	671,947

[1] Data published in "El Telegrafo" of Guayaquil, July 10, 1932, in an article by Dr. Francisco Banda C., Consul General of Ecuador in New Orleans.

UNITED STATES IMPORTS OF TAGUA SEEDS[1]

	From Ecuador		From Colombia		Total from other countries		Percent. Ecuador
Year	Quintals	Dollars	Quintals	Dollars	Quintals	Dollars	
1928	124,543	334,651	73,598	184,676	233,249	662,601	53 %
1929	182,619	444,026	66,030	122,162	266,330	648,512	67.85%
1930	96,058	190,566	19,782	19,547	125,778	253,928	76 %
1931	166,118	144,833	7,464	6,496	179,478	382,131	92.62%

[1] Close inspection of this table reveals that the percentage figures, if based on the other figures, are incorrect. The author could not be consulted before printing, and correction will therefore be made in the next issue. [Editor].

Prices from 1928 to 1944 can be calculated from the preceding tables.

Tagua has always entered the United States free of customs duties and taxes, but during the war, despite this freedom, consumption diminished considerably. In 1931, a year of heavy depression, the United States nevertheless imported from Ecuador about 70,060 quintals more of tagua than in 1930, and 41,575 more than in 1928, and almost the same quantity as in 1929. During recent years the tagua market has been completely inactive because of the war and the probable large stock piles that industries had in storage. To this must be added the fact that tagua must not only compete with the dictates of fashion, which do not favor tagua buttons, but must also face the competition of artificial products, such as those of casein, which have been so perfected that little by little they are replacing the natural product. Tagua must also compete with the synthetic product known as "bakelite". It must also be borne in mind that the button industry uses not only South American tagua but also African tagua or Dum nut from the Sudan, many hundred quintals of which have been used because of its low price. The inferior quality, however, and the small size of this African product, as well as the moderate price of Ecuadorian tagua permit the latter to compete advantageously.

Native Uses of Tagua

All parts of the tagua palm are utilized—roots, stems, leaves, floral spathes, fruit, seeds, *etc.* The following account of these uses is based upon the author's observations in the Provinces of Esmeraldas and Guayas and in the western sections of the Provinces of Bolivar and Chimborazo.

The roots are used as medicaments in some sections, diuretic properties being attributed to them. They are also used in the preparation of drinks after boiling.

The solid stem has a very hard exterior and because of this property is used, after being split longitudinally, in the laying of floors, in the same manner as "pambil" (*Iriartea* sp.?) and "guadua"

(*Guadua latifolia*); this use is not preferred in Esmeraldas, as in that Province there is an abundance of guadua, pambil and other fine woods. The stems, cut into sections 30 to 40 centimeters long, are used in some parts of the Guayllanac section as seats, in the same way as "cabuya" and agave are used in the Provinces of Tungurahua and Cotopaxi.

FIG. 3. Tagua seeds being sawn into slices by an electric rotary saw. (*Courtesy U. S. Dept. Agr., Off. For. Agr. Rel.*).

The "cogollo" or "yema" (apical vegetative cone) is utilized under the name of "guagra changa" as food in salad, curry, *etc.*, being first cooked for these purposes. The "guagra changa" is the aggregate of embryonic leaves, very tender and soft, which when used in this form is treated as though it were a cabbage head. The author has found this preparation quite palatable.

The leaves, large and pinnate, are used in the roofing and thatching of houses in the mountains, as well as in the villages. While travelling through the descending valleys of the western part of Bolivar Province—Telimbela, Tablas, Limones, Echeandia, *etc.*—as well as through the Bucay and Pallatanga sections, the author has noticed that the houses are exclusively roofed with leaves from the tagua which are known there as "cadi". In the western sections of Bolivar and Chimborazo Provinces "cadi" leaves are used from 350 to 2,000 meters above sea level, from Echeandia to above Limon, and from Bucay to Pallatanga. In the tropical and subtropical sections of Bolivar Province only "cadi" leaves are used in roofing. One hundred cut leaves, dry and fermented, sell for eight to 12 sucres, and in Esmeraldas up to 15 sucres. In Esmeraldas Province "rampida" leaves or "paja toquilla" (*Carludovica palmata* and *C. purpurea*), whose duration is even greater than that of zinc, are preferred. The author has seen cases where they have lasted more than 20 years in the mountains.

To use tagua leaves for roofing they are first submitted, after being cut, to a fermentation of eight to 15 days. Once removed from the tree and "desvenadas", as the natives refer to the condition of having the midrib cut out, the leaves are heaped in orderly fashion and covered for softening or fermentation. After fermenting they are ready for roofing. Their duration is from six to eight and even ten years, but the far-sighted mountain men repair the roofs of their houses every year before the beginning of the rainy season.

The long fibrous spathes, after removal of the inflorescence from within them, are fastened to handles and thus converted into very durable brooms. The manufacture and sale of such brooms may be seen in the Telimbela section of Bolivar Province. The fibres of the spathes are also used in the making of strong and durable rope and cord suitable for use during the "winters" or rainy seasons.

The seeds are of course the most used

part. When very young they are watery, and as they ripen they become progressively milky, curdy, viscous and gelatinous. In these different stages they are used as a drink which is somewhat sweet and as pleasing as or more so than coconut water (*Cocos nucifera*). When the content of the seeds is milky it resembles rice water and is very pleasant to drink. When it has reached the gelatinous stage it is eaten with a spoon. In the mountains the fruit or the seeds are gathered only by machete. At maturity the originally liquid endosperm of the seed is replaced by the very hard ivory-like substance known as "vegetable ivory".

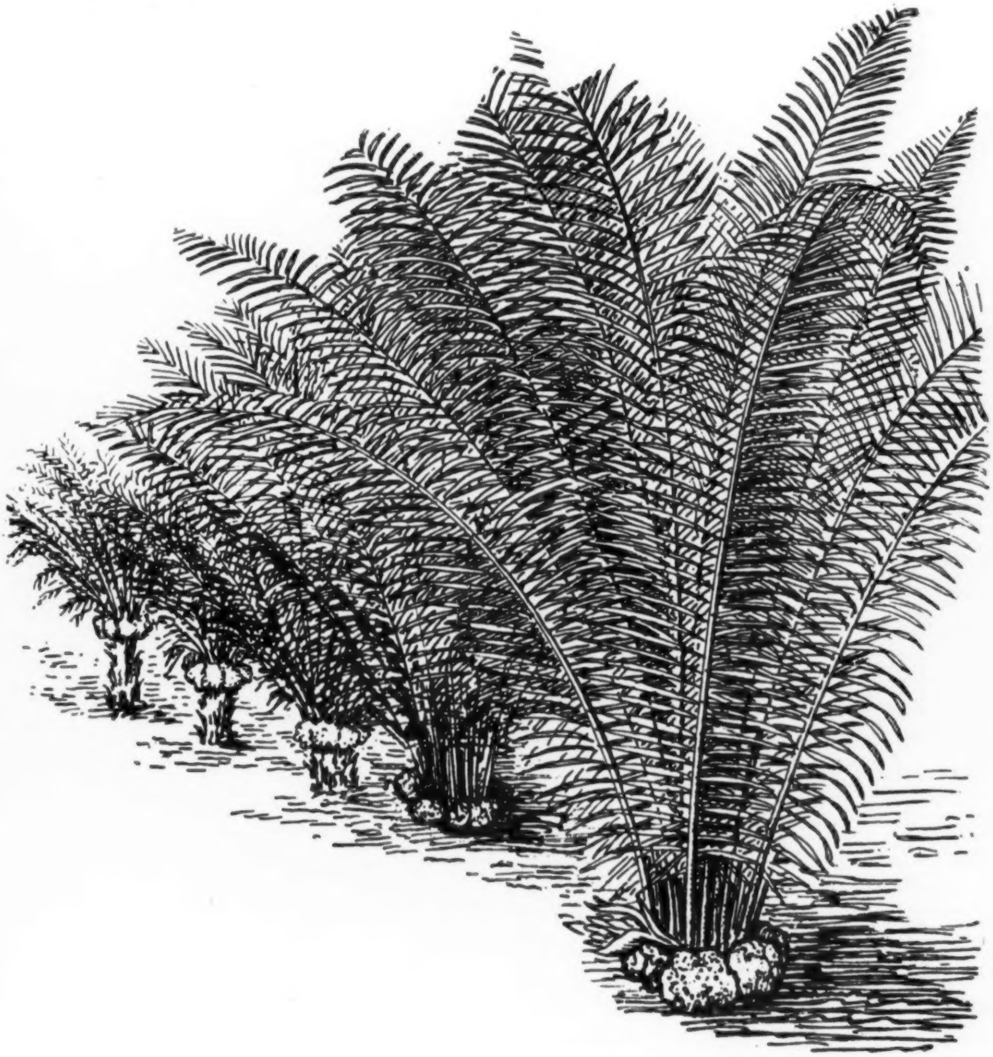


FIG. 4. A group of female, or pistillate, tagua palms, showing their acaulous nature and the position of their fruits on or slightly above the ground.

For commercial trade the seeds are converted into "shelled tagua" by removal of the thin perisperm or "concha", as it is called in Manabi and Esmeralda, which envelopes them.

Industrial Uses of Tagua

Up to about 75 years ago Ecuador paid no attention whatsoever to tagua, nor did it consider the seeds to be of commercial importance. The experiments conducted primarily in Germany were responsible for the birth of the industry in this commodity by making known the varied uses to which this hard seed could be put, not only in the button industry but also in the manufacture of dice, articles of ornament, chess pieces, umbrella and cane handles, and other items of domestic use. All these objects are elegantly manufactured from this raw material because of the ease with which it can be cut, carved, polished and made to absorb any coloring material.

Since the beginning of its industrialization, tagua has been found suitable for the manufacture of buttons, and today that is its principal use. In the last few years the jewelry industry has been using tagua more and more in the manufacture of charms, pins, small busts and other articles inlaid with it in gold and silver.

FIG. 5. A caulescent tagua palm with its large fruits known as "mazorcas", "mocochas" and "cabezas de negro".

All these uses have notably influenced the increase in demand for this nut in the last decades. More than 25 factories have been established in the United States dedicated to the transformation of this raw material into articles of daily use. The toy industry, too, has found an excellent material in these seeds.

The principal manufacturing centers for tagua are established in Rochester, New York City and Brooklyn, New York; Newark, New Jersey; Springfield, Massachusetts; and Waterbury, Connecticut. It is claimed that the city of Rochester has the largest and most modern plant in the world for the manufacture of products from tagua.

In Ecuador, especially in Riobamba, Ambato and in the Panóptico of Quito, tagua is much used for the manufacture of small figures and toys. An infinite number of imitations, chess and checker games, busts in miniature, cane handles, dice, statuettes and many other things that imitate real ivory are made of it. All these articles can be bought in the markets of Riobamba and Quito, and are really artistic. It must be borne in mind, however, that they lose their hardness when in water for a long time, although they recover it when exposed to air.

Perpetuation and Economic Future of Tagua

The "macado" method of harvesting tagua is exceedingly destructive and must be abandoned if the commercial sources of the seeds in Ecuador are to be perpetuated. By this method the mountain folk and negroes, seeking only the best way of collecting more and more tagua, cut the young fruit and often the whole palm which never sprouts. The tagua collected while young is forced to ripen by being covered with earth. It does not matter to the negro or "montuvio" whether the forests are destroyed or not; the only thing that interests him is to collect the tagua and get money for his expenses and vices.

To correct this situation there should be governmental regulation of tagua exploitation, as well as of other forest species. During botanical excursions through the coastal areas of Ecuador the author has observed with much sorrow how whole sections of natural forests were destroyed by fires under the pretext of clearing for cultivation of corn, or for pasture, *etc.* As tagua constitutes a natural wealth, not only potentially but actually at present, it is necessary and important to introduce agricultural technology and a law regulating the harvesting of the seeds.

For agricultural experiments in tagua the experiences of the Esmeraldians, especially the inhabitants of the Santiago River basin where tagua has been cultivated for some 40 or 50 years, would be of good use, and the tables of observations contained in this article might well serve as additional data on which intelligent regulation might be based. If Ecuador does not protect and develop its natural resource of this economically important plant product, such development may be taken from the country and pursued elsewhere in the world, as was the case regarding cinchona and rubber.

Experimental cultivation of tagua should be started now. There is in Ecuador at present an Agricultural Experiment Station under the direction of American technicians, so experiments should be initiated on the agricultural fields of that institution. The Ministry of Agriculture, now called the Ministry of Economics, should formulate practical rules or instructions, but unfortunately this Ministry does not have a real technical department for forest affairs. The creation of a Botanico-Forestal Department as a dependency of the Ministry of Economics is necessary and urgent to be able to regulate technically and watch over all the resources of the country. The author presented this suggestion in 1934, but 14 years have passed and it still has not been put into practice.

Plants for Special Uses

Dependence of the United States upon foreign sources of Belladonna, Henbane, Stramonium, Digitalis, Ergot, Pyrethrum, Rotenone and numerous other plant products has stimulated attempts to produce the necessary crops domestically.

D. M. CROOKS

U. S. Department of Agriculture

Introduction

MEN have fought wars, gambled fortunes, roamed the seven seas, and lived and died for possession of a group of plants that many people have never heard of. They are the medicinals and other botanicals of specialized use, a miscellaneous lot and a vital one.

Some are obtained in this country from wild plants. Others are cultivated in a small way. A few are in the experimental stage of cultivation, testing and development. Some are imported most of the time and grown here only when we cannot get them elsewhere.

From belladonna (*Atropa Belladonna* L.), henbane (*Hyoscyamus niger* L.), digitalis (*Digitalis purpurea* L.), stramonium (*Datura Stramonium* L.), ergot (*Claviceps purpurea* (Fr.) Tul.) and poppy (*Papaver somniferum* L.) are obtained crude drugs that yield alkaloids and glucosides that go into many medicinal preparations. They and others like them are highly important to our national welfare and economy—to the health or very existence of many of us. To some people, the preparations mean the difference between living and not living; to others, they are merciful in easing pain. Other plants yield pyrethrins and rotenone for insecticides that help us keep healthy by killing insects without harming man or beast. Red squill (*Urginea maritima* (L.) Baker) is another; it produces a poison fatal to rats and mice but not injurious to humans, pets and farm animals.

Almost all plants yield some tannin. The dried leaves of sumac (*Rhus copallina* L., *R. glabra* L., *R. typhina* L.) and the dried roots of canaigre (*Rumex hymenosepalus* Torr.) often have 20 to 30 percent tannin, seemingly a large enough amount of this complex chemical product to have commercial possibilities. These are of particular importance now that other natural stores, like the tannin-yielding oaks (*Quercus montana* Willd., *Q. velutina* Lam., *Q. borealis* Michx. f., *Q. alba* L., *Lithocarpus densiflora* (Hook. & Arn.) Rehder) and chestnut (*Castanea dentata* (Marsh.) Borkh.), are almost gone.

A wide variety of plants, *e.g.*, celery (*Apium graveolens* L.), marjoram (*Origanum Marjorana* L.), thyme (*Thymus vulgaris* L.), peppermint (*Mentha piperita* L.), spearmint (*Mentha spicata* L.), sage (*Salvia officinalis* L.), caraway (*Carum Carvi* L.), *coriander* (*Coriandrum sativum* L.), mustard (*Brassica hirta* Moench, *B. nigra* (L.) Koch), paprika (*Capsicum frutescens* var.) and other herbs and condiments, yield flavors that whet our appetites and make our foods more palatable. The flavoring substances in them are usually volatile materials commonly called essential oils, or some constituent of such oils. We have become so accustomed to using them that any disruption of supplies creates new problems of production for our farmers.

The seeds of many plants yield oils which have important uses for food and in industry. For example: The oil of the caster-bean (*Ricinus communis* L.) has become a major item for industrial use because of certain specific properties, discussed later. Seed of safflower (*Carthamus tinctorius* L.) and perilla (*Perilla frutescens* (L.) Britton) yield oils with special properties that may be adapted to important industrial uses.

Supplies of medicinals, *e.g.*, mandrake (*Podophyllum peltatum* L.), ginsing (*Panax schinseng* Nees C. A. Mey), goldenseal (*Hydrastis canadensis* L.), blood root (*Sanguinaria canadensis* L.), cascara (*Rhamnus Purshiana* DC.) and a host of others of lesser importance are collected mainly from forested regions, mostly in the mountain country of western North Carolina and Virginia and eastern Tennessee. The exceptions are cascara and digitalis, collected in the Northwest. Many of them, or the products from them, are used in this country and are exported.

Usually we import a number of important medicinals. Belladonna, henbane, digitalis and stramonium, or the products from them, are either imported or grown here as war and peace dictate our freedom in commerce. Before 1914 almost our whole supply of them was imported; encouraged by high prices during the First World War, we began to cultivate most of them. After that war they were not grown except in a few special gardens maintained by Federal agencies, State stations or private concerns. Again in 1940 history repeated the flurry of the earlier war to get a stock of supplies; then came sky-rocketing prices when no stocks were available. Also soon came the speculative interest and a rush to obtain seed and instructions on how to grow these new crops. Now there is another decline in domestic production because of the anticipated supplies from countries that previously furnished such products.

The agricultural problem connected with the introduction of these crops or development of a plant that will provide products for special uses is not one of acreage utilization or volume production. The first problem is one of varieties and species suitable for our needs and how to get sufficient seed stocks of them. Next is the question of soil and weather and the adaptation of the particular variety. It is also a question of fitting a new crop into our pattern of agriculture and who is to do the job. With actual production come the problems of handling the crop and methods of seeding, cultivating, harvesting, curing and drying. Disease and insect control must be taken into account. Many of the products obtained from such special crops, in order to bring the highest returns to the grower, must be of the quality expected or demanded by the trade. The Federal Food, Drug, and Cosmetic Act establishes certain standards of purity and quality for products that are used in medicines and foods, and the producer must strive to meet the standards by handling his crops according to approved practices that assure maximum quality and price.

Plants for Medicines

Belladonna. Belladonna is an important medicinal. Approximately 200,000 pounds of the herb and root were imported annually from central and southern Europe between 1931 and 1940. During that decade there was essentially no cultivation of the plant in the United States. From the time most of Europe became involved in the war, few or no supplies of the drug came in.

Fortunately years of experimental work and previous experience with the crop in various sections of the country provided a store of valuable information. Summarized, this information indicated: That belladonna is best adapted to northeastern, north-central and western Pacific coast climates; the crop requires considerable labor, so that a grower

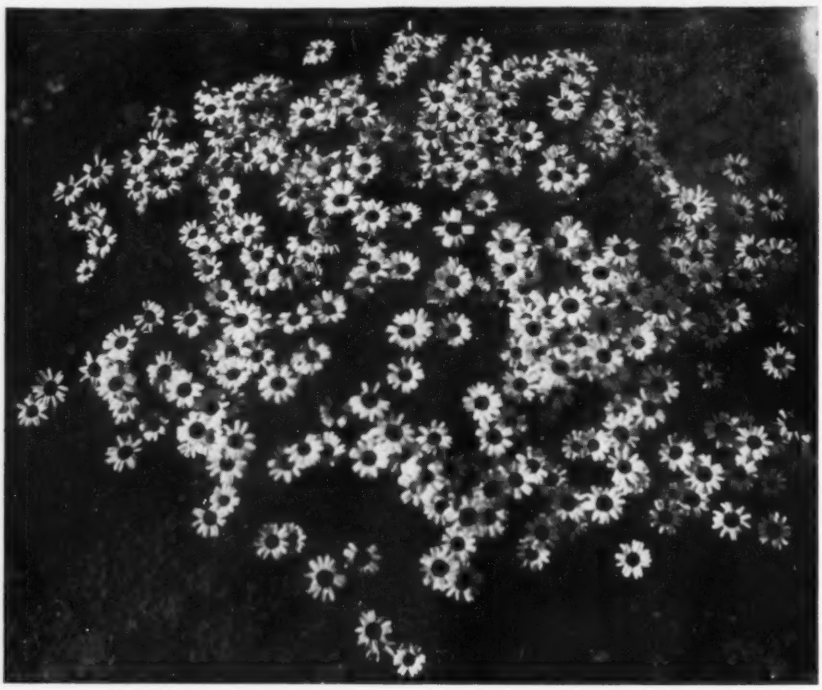


FIG. 1 (*Upper*). A belladonna plant (*Atropa Belladonna*), about two feet tall, the leaves ready to be harvested for extraction of their alkaloids, chief among which are hyoscyamine and atropine, used medicinally for various purposes.

FIG. 2. (*Lower*). Pyrethrum (*Chrysanthemum cinerariaefolium*), the flowers of which are the source of the much used insecticide bearing the same name.

should not plant more than a few acres; experience in growing plants in seedbeds with subsequent transplanting to the field is desirable in establishing the crop; facilities for artificially drying the crop are necessary; the total area needed does not greatly exceed 500 acres if a reasonable average yield is obtained; a crop grown from seed of a proved variety may be expected to yield a botanical satisfactory for medicinal uses.

That information was the basis for developing a plan that could be expected, with reasonable certainty, to provide our civilian and military needs without greatly overplanting and wasting effort.

Before the First World War a variety of belladonna was selected that when grown under favorable conditions had an alkaloid content about twice the minimum required by the United States Pharmacopoeia. The strain was maintained from year to year in the Department's experimental testing beds in Arlington, Va., and later at Beltsville. In 1941, when we had almost no belladonna seed in this country, the experimental plantings were increased to yield enough seed for a commercial acreage. This seed, with an additional amount available from pharmaceutical manufacturers, was used to establish plantings in five regions among farmers familiar with growing tobacco, which in many respects is handled the same way as belladonna. The localities selected were in eastern Pennsylvania, south central Virginia, western Ohio, southern Wisconsin, northwestern Tennessee and southwestern Kentucky. Most of the seed provided for production in those areas came from the selected stock that had been proved and grown from year to year since 1914.

FIG. 3 (*Left*). Stem of a castor-bean plant (*Ricinus communis*) with leaves, a spike bearing nearly mature and characteristically spiny pods, and a young flower-bearing spike. The oil of the beans is extensively used industrially in addition to its lesser medicinal use.

FIG. 4 (*Right*). Stem of belladona (*Atropa Belladonna*) with leaves, flowers and fruits.

A little more than 400 acres were planted with the seed distributed. There were also a few scattered plantings in

FIG. 5. Henbane (*Hyoscyamus niger*) about 40 inches tall and in bloom during the second year of its growth. The leaves are the source of the medicinally important alkaloids hyoscyamine and scopolamine.

other parts of the United States. The total production, about 350,000 pounds in 1942, exceeded expectations. It is estimated that about two-thirds of it was grown in Pennsylvania and Wisconsin. In Ohio the results were only fair. In Virginia, Tennessee and Kentucky many failures occurred, and the returns were generally poor. The quality of the botanical varied with regard to color but averaged well above the requirements in alkaloid content. The cost of production was generally high, and varied greatly, but most growers found the enterprise profitable, considering the price paid for the crop. The highest cost was in Pennsylvania and Wisconsin, but there the acre yields were correspondingly large. Seedlings were grown in seedbeds and greenhouses. Those in greenhouses were more expensive but generally larger, transplanted with less loss and earlier in the season, and usually yielded better. Diseases and insects were largely responsible for failures in Virginia, Ohio and Kentucky-Tennessee where damping-off fungi caused excessive damage in seedbeds, greenhouses and fields. Also a stalk borer destroyed many acres in the area. Complete drying in barns used for air-curing tobacco was not generally satisfactory, especially in Pennsylvania and Wisconsin. Facilities for artificial heating and rapid drying had to be provided, particularly in areas with wet weather.

The wartime production of belladonna was supported by concerns that were experienced in importing, marketing or processing botanicals. They contracted with farmers to purchase almost the entire crop. By fitting the problem of belladonna supply into our pattern of agriculture and commerce, our farmers solved the problem in a highly effective manner, although many difficulties arose and were solved in part during that period of production.

Since 1942 the acreage of belladonna has greatly declined; now practically none is grown commercially in this country. Prices offered for it would seem to warrant growing it, but individuals or concerns cannot risk the unfavorable effect on prices of the arrival of imports from countries that previously supplied our needs. The great amount of hand labor required to grow, harvest and cure the crop becomes the determining factor of production when competition is with foreign countries where costs of labor are lower than our own. Whether any commercial production will be established in the United States will be determined only when the offering of imports is known. Some growers are now experienced in growing the crop, and only a few who can operate most efficiently by taking advantage of procedures and practices established by research and testing can produce the botanical at a cost that will come close to previous imports at 15 to 20 cents a pound.

Henbane, Stramonium, Digitalis, Ergot. Henbane is another botanical in fairly consistent demand. During both world wars a few people in almost every part of the United States attempted to grow henbane because of high prices offered for it. Tests have been made in various soil and climatic conditions and with several varieties in almost all parts of the country. Cultivation has been successful only in localities with a relatively cool growing season. A small acreage in Michigan provided most of the production from cultivated plants during the two wars. Between the wars about 100,000 pounds of two species were usually imported annually. The high susceptibility of the plant to the mosaic disease of tobacco entirely eliminates the possibility of growing it in many localities. Henbane has escaped cultivation and grows wild in mountain valleys in the northern Rockies, chiefly in Montana where most of our domestic supply was collected during the war. Black henbane, *H. niger*, is the official one, but another species *H. muticus* L., from Egypt is often imported for the extraction of certain alkaloids.

Stramonium is a common weed throughout the eastern half of the United States. It is relatively easy to cultivate but difficult to harvest and dry as an acceptable botanical. Between the wars about 200,000 pounds a year were usually imported at relatively low prices. Small scattered plantings were grown during the war, and a considerable amount was obtained by collecting wild plants. Different strains varied considerably in alkaloid content, but all varieties that we observed and tested appeared to meet established standards if properly harvested and dried.

A few growers produced dried stramonium leaves as a profitable enterprise for two or three years during the early part of the war. Later, stramonium was produced in Argentina and imported at prices lower than our cost of production, so our farmers stopped growing it before the end of the war.

A little known and unusual use is made of the stramonium plant in places in the South where nematodes damage tomato plants. Stramonium resists nematodes, and by stem grafting the tomato plant on it, which is easily done, tomatoes normal in flavor and appearance can be grown. The practice was recommended during the war to assure a better supply of tomatoes from home gardens in the South. However, the poisonous alkaloids present in stramonium are apparently produced in the roots and then pass through the plant sap into the tomato fruit, possibly in sufficient quantity under some conditions to be a serious health hazard.

Digitalis, which is widely grown as an ornamental, has been known since ancient times as an important remedy for

FIG. 6 (*Upper*). Red squill (*Urginea maritima*), about five years old, growing in a 12-inch pot. The bulbs contain the specific rodent poison scilliroside and thus are the source of an important raticide not injurious to humans, stock animals and pets.

FIG. 7. (*Lower left*). Stramonium (*Datura Stramonium*) with leaves ready for harvesting. The dried leaves and tops furnish alkaloids used principally to relax the bronchial muscle in the bronchial spasms of asthma.

FIG. 8 (*Lower right*). Stramonium stem with leaves and mature spiny capsules.

certain heart ailments. For many years there has been limited cultivation of it in this country, usually by pharmaceutical concerns that make special products from digitalis. Our planting tests have proved that cultivation is successful only in the cooler climates because of the severe injury caused by red spider. In mountainous parts of the Pacific Northwest a considerable amount is collected from plants growing wild. The growth habit and character of the many forms of the official digitalis vary greatly; however, all forms, if properly harvested and dried, appear to meet prescribed standards. The glucosides in the botanical are not very stable, and usually new supplies of the drug are obtained annually. In the period between the wars about 50,000 pounds were imported each year. During the second war a number of small acreages were grown in some of the northern States. Plantings were established by transplants from greenhouses. Cultivating, harvesting and drying were essentially hand operations.

During the last years of the war another species of digitalis (*D. lanata* Ehrh.) was grown on a limited acreage, chiefly in Wisconsin and Pennsylvania. This production was for a special botanical in foreign demand at that particular time. The crop was handled in the same way as the other species.

FIG. 9 Digitalis (*Digitalis purpurea*) in the autumn of the first season's growth. The leaves, here with petioles about 15 inches long, furnish the drug digitalis, extensively used as a cardiac stimulant and tonic and as a diuretic.

The medicinal ergot consists of the sclerotium of a fungus that grows on rye grain while it is developing in the seed head. In the prewar years about 200,000 pounds were imported annually, on the average, for the extraction of several

complex alkaloids. When the supply was cut off from Europe the problem was one of removing the ergotized grains from rye grain or waste grain screenings. The cost was high because of the hand labor required, but several concerns successfully used this method, chiefly near large grain centers in Minnesota. Adequate supplies were thus obtained, and no attempts were made to produce the

FIG. 10. Rustica tobacco (*Nicotiana rustica*), the leaves of which yield about twice as much nicotine as do those of the ordinary tobacco (*N. Tabacum*). This feature makes it valuable as the source of nicotine for insecticides.

drug by artificial inoculations of the rye crop.

As a safety feature in our national security we must maintain our ability to supply our needs of botanicals through maintenance of seeds or planting stock of types suitable for planting. To do this some plants must necessarily be grown each year in various locations to test their adaptation, behavior and resistance to diseases and insects.

Plants for Killing Insects and Rats

Pyrethrum (*Chrysanthemum cinerariaefolium* (Trev.) Bocc.) has yielded one of our most useful insecticides. The pyrethrins, the active ingredients in the dried flower heads, quickly kill many insects and are harmless to man and other mammals. World production has shifted from southern Europe to Japan, then to Kenya, Africa, within the past 30 years. Experimental plantings have been made in almost all parts of the United States and more recently in most countries of this hemisphere. Annual imports during the five years before the war averaged about 15 million pounds.

The world demand greatly increased during the war, and the supply had to be rationed among the allied countries. Diseases from several causes have been extremely destructive to this crop in most areas in this country, especially in the warmer sections. Good growth has occurred in several locations with well-drained soil and a cool growing season. Especially good yields and quality were obtained in Pennsylvania, but the cost of production appeared excessive. Much hand labor is required to pick the flowers, although new machines have been designed to reduce the cost of this operation. Some attempts have been made at commercial growing but without much financial success. A program that is under way to improve varieties for high pyrethrin content, disease resistance and adaptation to soil and climatic conditions in this country should improve the chances for domestic production. New insecticides, such as DDT, supplement pyrethrum but do not replace its special use for certain purposes, especially in the control of household insects that require quick killing and for insects on vegetable

and fruit crops where insecticides otherwise non-poisonous are necessary.

Many plants, especially those believed to have some poisonous properties, have been tested in the world-wide search for insecticides. Rotenone, a potent poison to many insects, occurs in sufficient amount in derris (*Derris* spp.) and cube *Lonchocarpus* spp.) to be extracted for commercial insecticides. Both of these plants require a tropical climate and cannot be grown in the United States. Following a clue that certain plants in northeastern Texas were used to poison fish, a small amount of rotenone was found in the roots of a weed called "devil's shoestring" (*Tephrosia virginiana* (L.) Pers.). A careful examination of devil's shoestring growing throughout the eastern and Gulf Coast States revealed that only a few plants in certain areas possess rotenone in measurable quantity. Plants selected and improved through breeding now yield consistently $2\frac{1}{2}$ to 3 per cent rotenone. A few individual plants have yielded two to three times that amount, which is equal to that found in derris and cube imported for commercial use. These high-yielding plants are not yet available for commercial introduction. Crop problems in the field, such as occur when any new plant is introduced as a crop, have not been solved. However, not too far in the future farmers in the Gulf Coast States may be able to grow the insecticide needed on their own farms. Grinding the roots sufficiently fine to be effective as an agricultural insecticide may be a difficult problem. It is not yet solved.

FIG. 11. (*Left*). A paprika plant (*Capsicum frutescens* var.) with mature pods which provide the well known condiment.

FIG. 12 (*Right*). Peppermint (*Mentha piperita*), the dried leaves and flowering tops of which furnish the flavoring agent.

Early in the war we were critically short of red squill for making a rat poison that is safe to use where human or livestock food might become contaminated. Only a fraction of the squill bulbs imported were found to contain the poison; at least five years are required to grow a usable bulb. The soil and climate needed are found in the coastal region of extreme southern California. Some stock is being developed for possible production through either cultivation or plantings that would be allowed to go unattended.

Nicotine, an important insecticide, is generally extracted from waste tobacco (*Nicotiana Tabacum* L.) of the tobacco industry or from the excess crop diverted to this purpose. Another species of tobacco (*N. rustica* L.), commonly referred to as rustica tobacco, has more nicotine and has been tested in several parts of the United States. When grown on fertile irrigated soils, rustica tobacco has consistently produced 150 pounds or more of nicotine to the acre, which is approximately double the quantity obtained from ordinary tobacco. Diseases and insect hazards to production, including curley top, transmitted by leaf hoppers, nematodes and stalk borers, were encountered in some areas to such an extent as to limit production. Temporary drought any time during the growing period proved to be a serious hazard in most humid regions. Heavy irrigation, late harvesting, use of improved strains and topping, followed by systematic suckering, have yielded as much as 300 pounds of nicotine an acre. But on the basis of prices commonly paid for low-grade or damaged leaf tobacco from which nicotine is generally obtained, even such a high yield does not offer a wide margin of profit.

Plants for Flavors

The demand for plants that yield flavors and the efforts to obtain them have profoundly affected the history of the world.

The American market for spices, essential oils and condiments is large, yet very few of them have been produced here except during the wars. The reason is chiefly one of economics, for a number of the plants are adapted to various sections. Competition with foreign production where family labor is cheap is difficult to meet, even though domestic products are of equal or better quality. Peppermint and spearmint are exceptions; they are well adapted to mechanized handling, and the acreage planted to them in the United States is large enough to warrant development of specialized machinery.

During the war many places were tested by trial plantings and commercial growing of condiment plants. Domestic sage, grown commercially in many States, partly replaced the million and a half pounds that were formally imported annually. Extreme variation in the types and quality of the plants was common. Selected varieties were developed, but they must be propagated by cutting to maintain their uniform quality. A wilt disease caused considerable loss, especially in poorly drained soil, and nematode injury was severe in the warmer climates. Other leafy condiments produced in scattered plantings were marjoram and thyme.

Caraway, celery, poppy, coriander and mustard seed are some of our most popular seed condiments. Before the war we imported about 30 million pounds of them a year. Only mustard seed is produced in important quantities in this country, mainly in Montana and California where during the war the annual production averaged about 40 million pounds. The growth or possession of *Papaver somniferum* is prohibited by the Opium Poppy Control Act of 1942 because of the dangerous drug in the plant. The poppy seed does not contain the drug

and can safely be used for food. An annual variety of caraway was selected and grown commercially in conjunction with flower-seed growing in California. Coriander also was grown in the southwestern United States where it was planted as a fall crop and harvested in the dry months of spring. Seed condiment production proved hazardous in moist climates because of the difficulty in curing and harvesting the seed.

FIG. 13 (*Left*). Castor-bean plant (*Ricinus communis*) with fruiting spikes.
FIG. 14 (*Right*). Canaigre (*Rumex hymenosepalus*), the root of which is a source of tannin.

Prewar imports of paprika for use as a condiment averaged more than 5½ million pounds annually. When the supply from Europe was cut off, many Americans became interested in the possibility of producing it commercially. The imported seed yielded plants with extreme variation in quality and yield. Paprika should not be grown near hot peppers because the two cross readily. Trial plantings were made in many parts of the country, and commercial plantings were established in Louisiana, South Carolina and California. A destructive wilt disease and insect pests have made it necessary to make as many as eight or ten applications of insecticide for effective control. Picking and drying require much hand labor, and equipment for washing and drying is expensive. Growers in California have conducted a selection program to improve quality by reducing the pungency and increasing the yield and uniformity of the fruit. After the war the acreage declined. The future of the crop will likely depend on the price of imports offered and the results of breeding and selection for improved quality, yields and resistance to disease.

Plants for Tannin

Most tanning materials have been obtained by utilizing accumulated stores of

the material in the form of forest products, such as oak and chestnut, the supplies of which are rapidly being exhausted. Since early times both imported and domestic sumac leaves have been utilized for specialized tanning of light colored leather. In the United States leaves of the black or dwarf sumac (*R. copallina*), white or smooth sumac (*R. glabra*) and staghorn sumac (*R. typhina*) have been harvested and sold to commercial tanners.

The growing of sumac under cultivation has been considered many times; war and the fact that the plants help to control soil erosion have encouraged the investigation of such a possibility. Experiments by Department workers showed that the percentage of tannin in the cultivated plants ranged from 15 to 37 percent and that the total yield of leaf varied greatly. Successful methods of propagating the plants and harvesting and drying the leaves were determined and found to require more hand labor than most farm crops. Variety selections for improved yields and quality are in progress. Extensive drying and harvesting tests were made in some parts of the country where commercial interests cooperated with public agencies and landowners in utilizing the native sumac during the war when tannin supplies were in much demand. Aside from experimental tests, no one has attempted to plant and grow sumac as a farm crop.

FIG. 15. (*Left*). Safflower (*Carthamus tinctorius*), the dried flowerheads of which are a source of red and yellow dyes. The seeds contain good edible and drying oil.
FIG. 16 (*Right*). Caraway (*Carum Carvi*), the source of the flavoring seeds.

Canaigre, a plant of the dock family, has large fleshy roots that have 10 to 35 percent tannin on a dry-weight basis. It is a native plant of the sandy desert washes of the southwestern States and has been utilized for its tannin by the Indians. Commercial attempts to utilize wild canaigre were made in 1891–1892,

and some sporadic tests were made early in this century. More recently, experimental testing has been undertaken to determine the possibility of growing canaigre as a crop to provide tannin. Extremely variable results have been obtained on yield of roots and tannin. However, ten tons an acre may be considered as an annual average yield of roots in regions adapted to growth when the plants are harvested two years after planting. Individual selections for improved plants have demonstrated the possibility of thus obtaining better strains for both total root yield and higher tannin content. A practical method of shredding and drying the roots in the sun, an important item in production costs, has been demonstrated. Besides the tannin the roots contain a considerable amount of sugar and starch which have practical possibilities if methods of extracting them can be developed that do not interfere with the tannin extraction. Canaigre has not yet been developed to the point that it can be grown and marketed as a tannin-yielding crop, although it is one of the most promising native plants that may be used to place tannin production on a farm-crop basis.

Plants for Oils With Special Uses

The shortage of drying oils for paints and varnish renewed interest in growing safflower during the war. Numerous varieties were tested in several parts of the country by growers and agencies conducting experimental work. Some of the preferred varieties made yields ranging from about 400 pounds to 2,000 pounds of seed to the acre and consistently yielded about 30 per cent oil. Some attempts were made to grow the crop commercially in Nebraska and Montana during the war; there was a considerable range in yields, the average of the harvested acres producing approximately 500 pounds to the acre. The returns from the crop were quite erratic, apparently depending largely upon seasonal factors that affected growth, incidence of disease and yields. Safflower as a crop has given most promise in Nebraska and Montana, although good yields of oil and higher yields of seed have been obtained under irrigation in other States, especially in Arizona, New Mexico, Texas, California and Oregon, where it would be in competition with other crops yielding a higher cash return.

Cultivation of the castor bean plant (*Ricinus communis* L.) and use of castor oil from its seeds has had a very sporadic development in the United States. Before 1900 castor beans were grown commercially in Illinois, Oklahoma, Missouri and Kansas, and the oil was used in a variety of ways as a lubricant and in some manufactured commodities. Later, cultivation was practically discontinued, but during the first world war it was seriously attempted on a large scale when the oil was much needed for lubricating airplane engines. Again, cultivation was discontinued after the war, except for experimental testing. Commercial attempts at cultivation were renewed after hostilities between China and Japan in 1937–38 produced a shortage of tung oil for paints and varnishes. In the meantime chemists perfected a method of modifying the oil to form what is now known as dehydrated castor oil, which has excellent drying qualities necessary for making paints, lacquers and varnishes, especially those for use where water- and weather-proofing properties are desired. The Second World War increased the need for a large volume of drying and non drying oils at a time when reduced importations of these seriously threatened to curtail military activities. Other important uses of the oil are for hydraulic fluid and for making soap, linoleum, oilcloth, printing ink, leather and textiles. Average annual imports of castor beans for the three years before 1938 were about 115 million

pounds; almost three times that amount was imported annually during the war years.

As a matter of preparation for possible commercial production in this country, intensive work was initiated in 1941 to determine the area best suited to production, to collect, evaluate and increase seed supplies of suitable strains from a mixture of many miscellaneous types, and to determine the most effective cultural methods and what production problems might be encountered by growers.

Experimental plantings at 167 locations in 1941, 1942 and 1943, along with several thousand acres of seed-increase fields, showed that the region of adaptation is determined by at least three major factors, *viz.*, disease, length of growing season and rainfall. In most of the Gulf Coast region the gray mold (*Sclerotinia ricini* Godfrey) disease caused severe loss by destroying the flowering spikes in all stages. Elsewhere in areas with growing seasons of at least 180 days the yields of the three common varieties, Conner, Doughty 11 and Kentucky 38, were good, ranging from a few pounds to more than 1,500 pounds an acre. Observation in Kansas, Oklahoma and Texas indicates that between 15 and 20 inches of rainfall during the months from April to September are essential to satisfactory yields. Excellent yields, running as high as 2,000 pounds an acre, were obtained with irrigation in the lower Rio Grande Valley and in New Mexico, Arizona, and southern California, but the varieties tested did not compete with high-value crops.

The area of adaptation for the varieties tested includes roughly the southeastern half of Kansas, Missouri, the southern third of Illinois, southern Indiana, the southern tip of Ohio, the western and central parts of Kentucky and Tennessee, Arkansas, all of Oklahoma except the Panhandle, the part of Texas north of Dallas and east of Lubbock, and the area within 50 miles of Corpus Christi.

Within the general area outlined the three main characteristics of the soil satisfactory for this crop are exceptionally good surface and under drainage, sufficient subsoil permeability to insure adequate movement of air and water and growth of roots, and the capacity to warm up readily in the spring.

In general, the cost of growing the crop was about the same as for cotton or corn, but the time required for harvesting was about twice that of corn. Varieties grown for seed increase were selected because of their genetic purity, yielding ability and non popping or non shattering characteristics. Machines were designed to shell the hulls from the beans, and some commercial concerns have manufactured and offered the hullers on the market.

The future of castor bean cultivation in the United States depends on the price and amount of beans available through imports and the success of a program to improve varieties. Some improved selections have recently outyielded the Conner, Kentucky 38 and Doughty 11. Further increases in yields and improvement in character of the plant that will help to mechanize the harvest will be contributing factors to establishing a castor bean crop. At least 200,000 acres could be put to use in growing the amount of castor beans used in our industries.

Curare and Modern Medicine

This deadly arrow-poison of South American Indians, concocted from the juices of a variety of plants, has found modern clinical use in the treatment of human ailments.

LOUIS V. BLUBAUGH and CHARLES R. LINEGAR
E. R. Squibb & Sons, New Brunswick, New Jersey

DURING the latter part of the sixteenth century Sir Walter Raleigh, returning from a voyage to the newly discovered continent of South America, introduced to the British Court a strange concoction employed as arrow poison by the Indians in the Orinoco Basin. The densely black, deadly drug, called "woorali" by the savages, was appropriately contained in a tiny wooden vial, the surface of which was carved with aboriginal designs and brightly colored. We must surmise that Sir Walter told vividly of its astounding lethal qualities and of the weird rites attendant to its preparation.

Other explorers, preceding or following in his footsteps, related bizarre tales concerning the potion, all clouded by inaccurate observations and over-dramatization. The preparation of the arrow poison—variously known as "woorali", "urari", "curari", "wourari", and by other names, depending upon the particular tribe or location—was a secret carefully guarded by the tribal priests and passed from father to son. The brew, it was said, was mixed and boiled to the chanting of witches, and contained not only the deadly poison from certain barks and stems, but also the burning poison of venomous ants, forked tongues of serpents, and other equally evil, awe-inspiring and magic ingredients. It was also stated that some tribes appointed a criminal woman to prepare the brew, and that when she fell dead from the fatal fumes the concoction was complete. On one account all tales were apparently agreed: there was no escape from the paralyzing deadly poison once it had touched the blood—there was no antidote, no cure.

Such tales, interwoven as they were with vivid accounts of black magic, doubtlessly discouraged any attempt at practical appraisal of the potion. Over 200 years expired before the therapeutic possibilities of the material were considered, although several early workers, notably French and Italian, had made a number of valid observations. The preparation itself, they found, was highly toxic, but the vapors arising during extractions were not deleterious. Its administration by skin puncture resulted in a paralysis of the voluntary muscles, but did not affect the action of the heart. It was quite ineffective by mouth, particularly if the stomach contained food.

Sir Benjamin Brodie (1811–12) was probably the first to record observations that respiration was affected by the drug, and that heart action might continue for some time after cessation of respiration. He further found that artificial respiration was in many instances an effective antidote. The first chemical separation of crude curare was reported by Boussingault and Roulin (1828) who obtained a syrupy substance which they called "curarin".

During the early part of the nineteenth century a number of famous explorers had observed and written concerning arrowhead poison and probably furnished the samples upon which laboratory

study was made. Humboldt (1807) was the first to describe the preparation of the material by evaporation and mixture of plant extracts. Schomburgk (1844), from his observation in British Guiana, reported that the preparation contained the extracts of six to eight different plants, the majority of which were poisonous. It was Schomburgk's contention that the chief source of the toxic preparation was the bark of a plant which he classified as a member of the Strychnos group and named it *Strychnos toxifera*—an unfortunate classification which contributed to the erroneous belief then prevalent that the fundamental action of the poison was strychnine-like or convulsant in character. Humboldt was probably the first to observe that the ingredients and lethal properties of arrowhead poisons differed according to the locality of the tribe.

The apparent stimulant or convulsive effects reported by earlier workers for crude preparations had led many to believe that strychnine was a constituent of curare. However, Bernard (1844), the renowned French physiologist, demonstrated that Indian arrow poison paralyzed the motor nerves, and also confirmed asphyxia as the cause of death. These findings were verified and extended by the German workers Virchow and Münter (1848) who also showed that the material did not produce convulsions. On the contrary, they concluded that it induced paralysis of the voluntary muscles followed by stupor and that death was due to failure of respiratory musculature.

Chemical study resulted in the isolation of several fractions from crude curare by aqueous extraction or alcohol separation. Preyer (1865) obtained the alkaloid curarin in crystalline form, and Boehm (1886–97) recognized crystalline alkaloids which he called curines. The preparations were obtained in low yield and varied greatly in respect to paralyzing properties.

These investigations apparently stimulated some therapeutic study, since, during the latter part of the last century in France and to a lesser extent in Germany, the material was applied clinically in cases of hydrophobia, tetanus and epilepsy. Toward the end of the century it appears to have been considered as a recognized therapeutic agent in otherwise hopeless cases. The dosage employed was probably low and the activity of the preparations questionable as no attempt was made to standardize the drug.

Reports of these various investigators impelled additional study, and slowly the veil of witchcraft and sorcery was lifted. Further laboratory study confirmed earlier findings that the poison affected muscular response to nerve stimulation. Several investigators interested themselves in its point of action in inhibiting nerve transmission, and it became recognized in the physiological laboratory as an interesting tool with which to demonstrate the relationship between nerve and muscle in the phenomenon of muscle contraction. Clinically it was employed, with not too encouraging results, in the treatment of certain spastic disorders, although a degree of success was reported in allaying and preventing the convulsions of epilepsy. Chemists in search of the active principle isolated alkaloids and described them as characteristic of "tube" curare[1], "pot" curare and "gourd" curare—an erroneous classification which later caused considerable confusion through attempts to classify different curare alkaloids on the basis of container types.

[1] Derivation of the word "curare" is somewhat obscure. It has been suggested that it may have been derived from Curwara, the name of a river in Guiana, but there is no certainty of this. It is now used universally to describe all Indian arrow poison.

During the early part of the present century the peculiar action of curare had become of great interest to laboratory workers and clinicians alike, although extensive studies of its action and possible therapeutic value were hampered

FIG. 1. South American Indians dip arrow tips for hunting into crude curare syrup—a thick gummy paste extracted from the bark and stems of plants of the Loganiaceae and the Menispermaceae families principally. The preparation is usually stored in gourds, bamboo tubes or clay pots.

because the sporadic supplies obtained by occasional travelers varied tremendously in composition and paralyzing action. Extracts prepared from such supplies were unstable and of variable activity, and, most important, there was no established method for standardization of the preparation in respect to potency.

Perhaps the greatest credit for dispelling misconceptions in regard to curare, particularly within scientific circles, should go to Richard Gill who gained the confidence of the Indians, overcame scepticism among clinicians and manufacturing chemists, and introduced to modern medicine the first significant supply of authentic curare. Gill lived in close association with and traveled among the South American Indians and was able to observe in detail the preparation of curare. He recorded accurately the process, determined the type and quantity of ingredients, and collected adequate samples for eventual chemical and clinical study.

Fundamentally the preparation of Indian curare consists of making a watery extract, either by steeping or by repeatedly pouring boiling water over the ingredients. This extract is concentrated by boiling, extraneous matter removed by straining and the concoction set aside to thicken into a gummy paste. The completed curare is stored in bamboo tubes, earthen pots and dried hollow gourds, from which type of container the terms "tube" curare, "pot" curare and "gourd" curare have been derived. Gill established that, contrary to early belief, the type of container had no relationship to the type of curare contained, since, in most instances, the container was employed according to the whim of the maker or according to whatever happened to be available.

Preparation of the curare was conducted by the medicine men or tribal priests in accordance with strict ritualistic custom which differed from tribe to tribe. In addition to inert ingredients, the active Indian curare contained highly toxic materials, such as snake venom and formic acid extracted from large quantities of giant ants by boiling. It was only with the greatest difficulty that Gill was able to obtain specimens of curare uncontaminated by such extraneous substances and to authenicate the material by plant specimens subsequently classified. He thus established that curare contained a complex of botanical ingredients representative of the Loganiaceae and the Menispermaceae families principally. He found that the Indians had learned much by trial and error concerning the toxic effects of their arrow poison, most of which has now been confirmed and expanded in the modern scientific laboratory. The Indian had learned that curare was innocuous by mouth, particularly if there were no breaks in the lip or mouth membranes, that the material was not effective on contact with unbroken skin surface, and that, in order to exercise its lethal characteristics, it must be introduced through the skin. The Indian was further aware that the drug produced numbness at the site of the wound and paralysis before death, and had even evolved a primitive antidotal procedure which proved to be remarkably effective. A wound inflicted by a curare weapon was immediately incised, the area ligated, if possible, and ordinary rock salt rubbed into the injured area. Great quantities of concentrated salt solution were also consumed and, unless the mechanical injury itself proved lethal, the victim usually survived.

Upon his return to this country in 1938, Gill was able to interest many prominent physicians in the potential usefulness of curare and to induce them to devote time and energy in exploration of a new therapeutic field. Finally in 1939 the entire story regarding curare

was brought to the attention of the research laboratories of E. R. Squibb & Sons, and, through the efforts of Holaday of the Squibb Biological Laboratories and of McIntyre of the University of Nebraska, a quantitative method for the determination of the active principle of curare was established. These studies

FIG. 2. Specimens of leaf and stem of *Chondodendron tomentosum* from which plant the black, gummy, crude curare syrup is extracted. From this crude preparation the pure alkaloid d-tubocurarine may be obtained.

resulted in the first preparation of predictable clinical action.

Purified curare extract for medical use, as distributed by E. R. Squibb & Sons under the trade name "Intocostrin", is prepared from crude, authenticated Indian curare. Special methods are employed by which most of the unstable inert substances comprising considerable bulk of the crude drug are eliminated. Sterile solutions prepared from the purified material are stable under proper storage conditions and are free from undesirable side-reactions. These solutions are accurately assayed on animals and tested in man. It should be mentioned that the crude curare is still prepared by the Indians of South America and that all material intended for ultimate use in medicinals is gathered and processed under the supervision of trained scientific personnel. Aqueous extracts of the bark and stems of the curare plant are prepared and concentrated to the consistency of a thick dark syrup. Shipment is made in modern metal containers.

The activity of Intocostrin is due principally to the alkaloid d-tubocurarine which was first isolated by King in 1935 in small amounts from an unauthenticated curare specimen and in 1943 by Wintersteiner and Dutcher in high yield from curare extracted from the single botanical species *Chondodendron tomentosum*. At a later date a solution of pure d-tubocurarine[2] was made available for clinical investigation and use. The availability of the standardized curare extract and later of pure d-tubocurarine chloride enabled therapeutic investigation to progress rapidly.

Laboratory and clinical study established that curare causes weakening or paralysis of skeletal muscle by interfering with transmission of nervous impulses in the synaptic connection between the nerve axon proper and the contracting elements of skeletal muscle, but the muscle itself does not lose its capacity to contract if directly stimulated. This action is dependent upon the concentration of the drug in the blood stream, and, because of its rapid excretion or destruction, its duration of action following a single therapeutic dose is short. It has been shown that curare does not prevent, at the motor nerve ends, the formation of acetylcholine, a chemical substance supposedly associated with neural transmission, but that it does antagonize completely the action of small amounts of acetylcholine on muscle responses. On the other hand, proper amounts of acetylcholine and of physostigmine or prostigmine, agents which potentiate or mimic the action of acetylcholine, tend to antagonize the action of curare.

Since several hypotheses are given by neurophysiologists of today for the sequence of events which follow the passage of impulses from the nerve axon and finally lead to the excitation and resultant contraction of skeletal muscle fibers, it is natural that there is some disagreement as to the exact locale and the mechanism of curare action in the synapse. Some recent theories favor the concept that during the normal transmission process a potential change or shift in polarization occurs at the myoneural junction (the end plate, sole plate or "effector substance") and this initiates the muscular contraction. This potential change may be due to formed acetylcholine, to changes in permeability of a membrane to certain ions, or to local action currents. Just how curare blocks the potential changes or causes them to decay, thus rendering them incapable of causing the muscle response, is not en-

[2] Solution Tubocurarine Chloride, prepared by E. R. Squibb & Sons, is a clear, colorless, sterile, isotonic aqueous solution of d-tubocurarine chloride. Clinically it gives results identical to those obtained with Intocostrin but may be preferred because of its lack of color, greater stability and chemical identity.

tirely clear. It is usually stated that curare prevents the action of physiologically formed acetylcholine on the effectors of the muscle. It is fitting in any discussion of curare to call to mind that, although one can see the results of nature's truly remarkable and complex physiological mechanisms in coordinated movements of the animal body and of the dramatic skeletal muscle relaxing qualities of curare, the scientific explanation of these actions remains as mystical as the history of the drug itself.

When curare is administered to the human subject, the first clinical symptoms, according to published observations, of relaxation induced by the purified, standardized available drug are haziness of vision, difficulty in talking, in swallowing and in keeping the eyes open, with weakness of the jaw, neck and leg muscles. This is followed by bilateral dropping of the eyelids and paralysis of the muscles of the neck, spine, legs and arms. Shallowness of respiration is the last symptom to appear. An interesting experiment on the human subject was performed by Smith *et al.* (1947) to determine the effect of crystalline d-tubocurarine chloride on consciousness and sensations of temperature, touch and pain. A co-worker was given two and one-half times the amount of this alkaloid required to paralyze respiration, and they report that "At no time was there any evidence of lapse of consciousness or

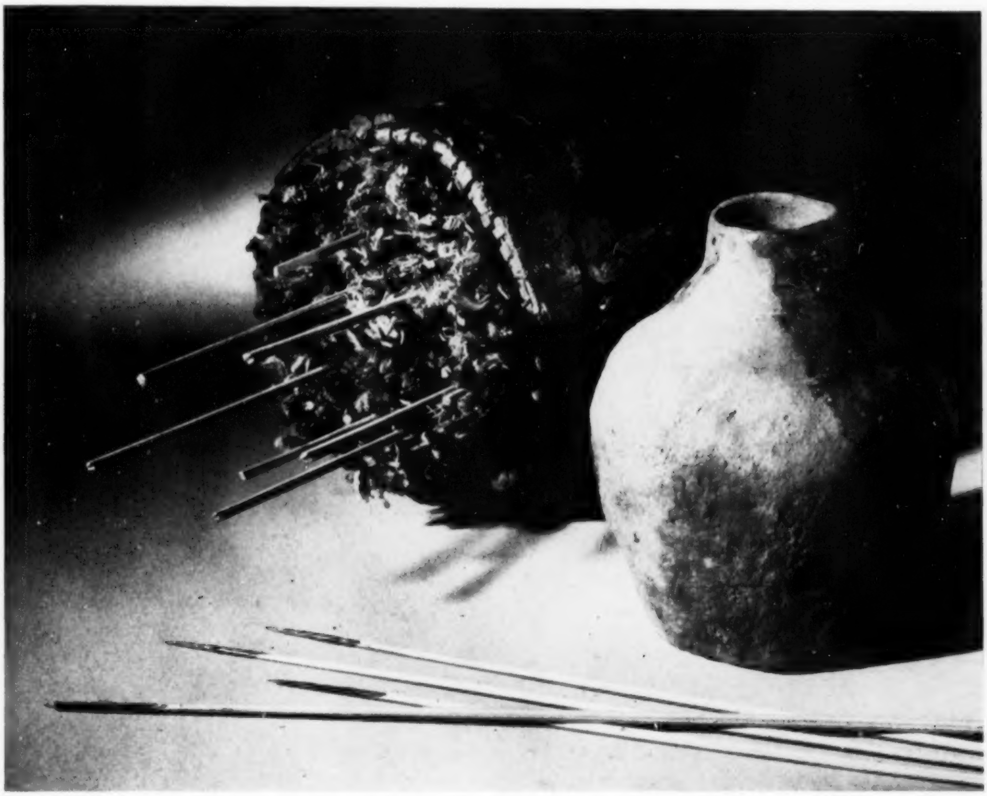


FIG. 3. The clay pot containing crude curare and the bark quiver filled with curare-tipped arrows are typical of those employed by the Indian hunter. The Indian's crude method of storage, administration and use represents the extent of primitive development of the product.

clouding of the sensorium". An earlier report showed that larger doses of curare cause unconsciousness but no analgesia.

The ability of curare to relax skeletal musculature is the essential characteristic which makes it useful in therapeusis. It is this property which made the material of value to Burman and later Bennett who reported extensively upon curare's relaxing effect in neurological states characterized by muscular rigidity and tremor. Curare noticeably diminished the hypertonia and involuntary motility. When administered to spastic children without fixed deformity, a transient relaxing effect was obtained which permitted physiotherapy. Satisfactory result was not, however, achieved in those cases in which muscle degeneration had occurred. In adult patients the temporary relaxation provided sufficient relief from painful spasm to justify recommendation of the drug for this purpose.

After employing curare upon a large number of spastic, paralytic children, Bennett, convinced of its safety and efficacy, next applied it as a means of preventing fractures which complicate metrazol shock therapy of certain mental disorders. It was largely due to his enthusiasm for clinical study of curare and through his use and report of it as a control of convulsions occurring with such treatment that the drug is now widely employed among psychiatrists. Curare does not appear to interfere with the central convulsant action of metrazol and therefore does not reduce the efficacy of the convulsant drug in this type of therapy.

During the last decade curare has been reported to be of value in treating the convulsions of tetanus, or lockjaw. Here, however, care must be taken to avoid deep curarization for long periods of time, since this in itself may tend to hasten shock in these cases. Its use has been extended to various types of peripheral muscle spasm and to spasticity and rigidity originating from injury to, or diseases affecting, the central nervous system. In order to avoid the fleeting effect and excessive reaction from aqueous curare preparation, Schlesinger (1946) used an oil and wax preparation of curare. This was first employed in a series of cases with spasticity following injury to the spinal cord and later extended to other types. With the use of this preparation beneficial results were obtained in spasticity without side effects or skeletal muscle paralysis and with but slight disturbance of normal voluntary function so that the majority of the patients were able to pursue their normal occupation during treatment.

When the relaxing effect of curare on spasticity had been established, the question naturally arose among clinicians as to its possible usefulness in the acute stage of poliomyelitis. Although there was fear on the part of many neurologists of accentuating the respiratory depression, accumulating evidence of the safety of the preparations prompted Ranschoff (1945) to treat a series of cases maintained under strict observation. His preliminary reports have encouraged other clinicians to expand the work originally initiated. The low dosage of curare used appears adequate to block nerve impulses associated with spasm while permitting transmission of impulses associated with voluntary movement. This results in reduction of abnormal muscle activity without loss of muscle strength, and the application of physiotherapy designed to prevent shortening of muscle becomes possible without excessive pain. Even in those cases with respiratory embarrassment, immediate and striking benefit has been reported following the use of curare. No claims, of course, can be made for a curative effect, but accumulated experience is demonstrating that the potential usefulness of curare in treating acute poliomyelitis exceeds by far the relief of pain.

It may become a most valuable adjunct to rehabilitation therapy.

Adequate muscle relaxation is a prerequisite of successful surgery, particularly abdominal. Before the introduction of curare, satisfactory muscular relaxation could be accomplished only through depression of the central nervous system activity by suitable anesthesia, frequently with considerable risk and disadvantage, because of undesirable operative and post-operative complications produced by the deep level of anesthesia required. By the use of curare the skeletal musculature of patients under light anesthesia can be relaxed sufficiently to permit major surgery without excessive central depression or resort to difficult nerve blocking procedure and, in cases of prolonged anesthesia with certain anesthetics, a minimum of vital tissue damage.

Griffith and Johnson (1942) were the first to publish a description of the clinical use of curare in conjunction with anesthesia. The drug was administered intravenously to patients under cyclopropane anesthesia, and they found it unnecessary to administer artificial respiration or stimulants. In each case complete and temporary muscular relaxation was produced. Largely through the results obtained and reported by Griffith, fairly general use of curare in anesthesia has been adopted. Since publication of the first report, both Griffith and later Cullen have extended considerably the number of anesthetic agents with which curare may be utilized. These include nitrous oxide, with which adequate muscular relaxation is not ordinarily possible, sodium pentothal and ether. Since ether has a curarizing effect itself, the dose of curare with this anesthetic agent has been reduced.

To date numerous papers have been published pertaining to the effectiveness of curare with various anesthetic agents and extending or modifying methods used in the early work. Curare has been advocated for use in facilitating laryngoscopy, esophagoscopy and bronchoscopy and for setting or reducing difficult fractures.

There is much yet to be learned about the drug, and the extent of its usefulness in modern therapeutics is far from complete realization. It is undoubtedly the closest approach to the ideal muscle relaxant yet discovered and as such will find usefulness wherever such an action is indicated in normal or pathological states.

And so curare, arrow poison of the South American Indian—subject of innumerable tales of witchcraft and sorcery carried even to this modern age by those who write knowingly of the "Winged Death", with total disregard for a multitude of scientific reports—has become an important clinical tool and therapeutic agent.

Bibliography

1. Brown, M. Webster: Curare, the magical and mysterious. *Medical Record* 140: 149, 1934.
2. West, R.: The pharmacology and therapeutics of curare and its constituents. *Proc. Roy. Soc. Med.* 28: 565, 1935.
3. King, H.: Curare alkaloids. Part I. Tubocurarine. *Jour. Chem. Soc.* (London) 1381, 1935.
4. Gill, Richard C.: White Water and Black Magic. Henry Holt and Co., New York.
5. Burman, M. S.: Curare therapy for the release of muscle spasm and rigidity in spastic paralysis and dystonia musculorum deformans. *J. Bone and Joint Surg.* 20: 754, 1938.
6. Bennett, A. E.: Preventing traumatic complications in convulsive shock therapy by curare. *J. A. M. A.* 114: 322, 1940.
7. Burman, M. S.: Clinical experiences with some curare preparations and curare substitutes. *J. Pharmacol.* 69: 143, 1940.
8. Bennett, A. E.: Clinical investigations with curare in organic neurologic disorders. *Am. J. M. Sci.* 202: 102, 1941.
9. Griffith, H. R. and Johnson, G. Enid: The use of curare in general anesthesia. *Anesthesiology* 3: 418, 1942.
10. Cullen, S. C.: The use of curare for the

improvement of abdominal muscle relaxation during inhalation anesthesia. *Surgery* 14: 261, 1943.
11. Wintersteiner, O. and Dutcher, J. D.: Curare alkaloids from Chondodendron tomentosum. *Science* 97: 467, 1943.
12. Cullen, S. C.: Clinical and laboratory observations on the use of curare during inhalation anesthesia. *Anesthesiology* 5: 166, 1944.
13. Griffith, H. R.: The use of curare in anesthesia and for other clinical purposes. *Canad. M. A. J.* 50: 144, 1944.
14. Ransohoff, N. S.: The use of Intocostrin (Curare) in poliomyelitis. *J. A. M. A.* 129: 129, 1945.
15. Griffith, H. R.: Curare: a new tool for the anesthetist. *Canad. M. A. J.* 52: 391, 1945.
16. Griffith, H. R.: Curare in anesthesia, *J. A. M. A.* 127: 642, 1945.
17. Bennett, A. E.: The introduction of curare into clinical medicine. *Amer. Scientist* 34: 424, 1946.
18. Gill, Richard C.: Curare: Misconceptions regarding the discovery and development of the present form of the drug. *Anesthesiology* 7: 14, 1946.
19. Schlesinger, Edward B.: Recent advances in the use of curare in clinical practice. *Bull. N. Y. Acad. of Med.* 10: 520, 1946.
20. Smith, Scott M., Brown, Hugh O., Toman, James E. P. and Goodman, Louis S.: The lack of cerebral effects of d-tubocurarine. *Anesthesiology* 8: 1, 1947.
21. McIntyre, A. R.: Curare, its history, nature and clinical use. University of Chicago Press, 1947.

Utilization Abstract

Curare. The name "curare", of unsettled derivation, has long been applied to a variety of deadly poisonous preparations made from the barks of various plants by Indian tribes of northern South America—especially in the region of the Orinoco, in Guiana and in Amazonia. It was used by them as an arrow poison, the tips of their arrows, and darts of blow guns, being dipped in the concoction to cause instant death to their prey. The manufacture and use of the stuff as such has almost disappeared and become a lost art, but the ingredients have since found modern medical application.

Identification of the plants used by the Indians has been difficult and is still incomplete, but it is established that several bushrope, liana species of *Strychnos* and species of *Chondodendron* and *Cocculus* have been the principal ingredients. Ingredients of secondary importance have been obtained from plants in the families Moraceae, Menispermaceae, Annonaceae, Leguminosae, Rutaceae and Rubiaceae.

Preparation of the poison from the bark of stems and roots of these plants was long a tribal secret and ceremoniously carried out. In general, it involved removing the bark, macerating and boiling it, and then evaporating the extract to a thick consistency. The resulting paste was smeared on the arrow heads.

The lethal effects of curare are due to its several alkaloids, only one of which, d-tubocurarine, has been made available by E. R. Squibb & Sons for experimental purposes. Clinical investigations have well established the use of curare as an adjuvant with anesthesia and to protect patients from injury in shock therapy. It has also been used in the treatment of chronic spastic conditions and in the control of convulsions in tetanus. *McIntyre, A. R., Curare—Its History, Nature and Clinical Use.* 240 pp. 1947.)

Sweetpotatoes—*World Production and Food Value*

The sweetpotato surpasses the white potato in its content of fat, carbohydrates, fiber, sugar, starch, calories and the vitamins carotene, riboflavin and pantothenic acid. In 1944, of more than a billion bushels produced throughout the world, over 600 million were raised in China, over 68 million in the United States.

J. S. COOLEY[1]

THE sweetpotato is not so well suited for shipment as are some other food crops, such as wheat, corn, beans, or even white potatoes, and hence it gets little or no mention in the reports of world commerce. No compilation of the total production of sweetpotatoes in the producing countries of the world is known to the writer. However, a summary of available statistics on production has been prepared recently by the Office of Foreign Agricultural Relations. This information is given in Table 1.

Although the sweetpotato is of tropical origin it can be successfully grown over a considerable range of climatic conditions. In this country, for instance, its production extends from the sub-tropical climate of the Gulf Coast to the mid-temperate region of Maryland and New Jersey, and, in small amount, even to New York State, Iowa and Kansas. In tropical countries it is a perennial plant, and storage problems do not need to be considered. In temperate climates storage must be used to preserve the roots for food and also for propagation purposes, and this brings up problems of facilities and prevention of spoilage.

In the United States the sweetpotato was grown in the South very early in the history of our agricultural development. It was at first a local crop and largely consumed locally. Gradually a market was developed in northern cities and in regions where it was not then grown.

Production statistics in this country give no earlier report than one of 1868 when production totaled 28,557,000 bushels (Agricultural Statistics, 1939). In 1900 the production was given as 45,684,000 bushels; in 1920 it was 76,999,000 bushels; and in 1936–45 64,200,000. These figures indicate that the production in this country has not increased in proportion to the increase in population. Spoilage may have been greater in the past than at present. The increased use of heated storage houses instead of bank storage, and other improvements in storage practices have probably had their influence in decreasing spoilage. The general per capita consumption outside the producing areas is probably much greater now than it was some years ago before marketing facilities were so well developed, but is still low compared with that within principal producing areas. Ferrier[2] estimated that the per capita consumption was two bushels in seven southern States and only 1/10 bushel in 21 northern States. The ten-year average for 1933–42 in the United States was

[1] Senior Pathologist, Division of Fruit and Vegetable Crops & Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture, Beltsville, Maryland.

[2] Bulletin 352, So. Carolina, 1939.

TABLE 1
PRODUCTION OF SWEETPOTATOES

Continent and Country	Year[1]	Average 1,000 bu.[2]	1944 1,000 bu.[2]
North America:			
Honduras	est. yrly.		(25)[3]
Mexico	1935–9	1,538	2,445
United States	1935–9	67,901	68,251
Bahamas[4]	....	....	....
Barbados[4]	....	....	....
Cuba	est. yrly.	6,182	(6,200)
Dominican Republic	1939	3,472	(4,000)
Guadeloupe	....	(17)	(20)
Leeward Islands[5]	est. yrly.	(20)	204
Puerto Rico	1935–9	1,680	(2,745)
Total, estimated	....	80,856	86,945
Europe:			
Spain	1935–9	2,441	(8,000)
Asia:			
British Malaya	1935–9	749	(1,500)
Ceylon	1939	(500)	815
China proper[6]	1937–9	495,212	608,136
French Indochina	1936–8	10,499	(11,000)
Japan, proper	1935–7	148,119	187,892
Formosa	1935–9	65,105	(66,000)
Korea	1935–9	9,976	(8,000)
Netherlands Indies			
Java and Munda	1935–8	50,498	(59,544)
Philippine Islands	1935–9	7,802	(3,000)
Total, estimated	....	788,460	945,887
South America:			
Argentina	1936–40	6,305	10,136
Bolivia	1938	177	(200)
Brazil[7]	1940	6,546	5,989
Paraguay	1938–40	4,334	(5,000)
Peru	1929	3,756	(4,000)
Uruguay	1936–40	1,582	1,683
Total, estimated	....	22,700	27,008
Africa:			
Belgian Congo	1936–8	3,894	(4,000)
French Equatorial Africa	1936–7	1,536	(1,500)
and Cameroun	1936–7	12,025	(12,000)
French West Africa[8]	1936–7	5,241	(6,000)
Madagascar	1936–7	14,730	(15,000)
Southern Rhodesia	1938–9	52	(100)
Union of South Africa	1936	1,359	(1,500)
Total, estimated	....	38,838	40,100
Oceania:			
Australia	1936–40	627	(450)
New Caledonia[9]	1936–8	8	(10)
Total, estimated	....	635	460
Total (estimated) of countries listed	....	933,930	1,108,400

Office of Foreign Agricultural Relations. Compiled from official sources, the publications of the International Institute of Agriculture and Foreign Service Reports. Includes office estimates, in parentheses, for countries for which specific data are lacking. The harvest in the countries of the Northern Hemisphere for the year shown is combined with that of the following year in the Southern Hemisphere.

23.5 lbs. per capita in comparison with 27.9 lbs. for the period 1910–19.

In northwestern Europe sweetpotatoes have not been extensively grown or consumed. They were introduced into Europe through Spain soon after the discovery of America. Some effort was made at that time to popularize this new food, but the European people apparently did not learn to like them as the people of some other countries have done. The climate is too cool in much of Europe for successful production of this crop, although the climate of southern France and other Mediterranean countries would probably be suitable for sweetpotatoes. Production there is of very minor importance. In eastern European countries the climate is not favorable, and all the information at hand indicates that there is very little production or consumption of sweetpotatoes in any of those countries.

In China and Japan the sweetpotato has been a highly prized food ever since its introduction. According to the meager information that we have, consumption is largely restricted to localities where it is grown. Storage facilities have been provided, but the highly specialized facilities necessary to market this perishable crop have not yet been developed there, and extensive shipping is not carried on. The sweetpotato was introduced into China (Province of Fukien) in 1594 as the result of a search for a crop that would relieve the frequent famines[3]. The culture of this plant rapidly increased and it soon came to be regarded as a boon in preventing famine. The Chinese still call it the "Dioscorea of Governor Kin", whose initiative led to its introduction. From Fu-kien the sweetpotato was carried to Formosa and to the Luchu Islands (Ryukyu; Okinawa) as early as 1605. Nugun, the superintendent of the Chinese settlement in Napa, the chief town of the Luchan Archipelago, presented a native village chief, Masatsune, with cuttings of the plant. The latter actively promoted it in his country. In front of Nugun's tomb a memorial pillar has been erected, and he is canonized under the name "Mmuushume", that is, "Ancestor of the Tuber".

[3] Laufer, B., Sci. Mo. **28**: 239–251. 1929.

The relative importance of this crop in these two countries may be estimated from the fact that China with a land area only about 20 per cent larger than that of the United States produces about eight times as many sweetpotatoes as we do, while Japan with less than one-tenth our land area produces two and one-half times as many bushels of this crop.

It is not possible to give the per capita consumption for most of the countries shown in Table 1. However, the approximate figures given below will show the wide variation in the relative importance of the sweetpotato and the white potato in different countries. The per capita consumption of sweetpotatoes in China is about 61 lbs.; in Japan, 118 lbs. in 1935 and 138 lbs. in 1944; in Mexico, 11 lbs.; and in the United States, 19 lbs. For white potatoes the per capita consumption in Japan is 58 lbs. and in the United States, 131 lbs[4]. These figures on

[4] The figures on per capita consumption for the United States exclude industrial and seed uses, while those for other countries include all uses.

Footnotes to Table 1.

[1] Some less than a 5-year average.

[2] Weight of bushel at harvest, of 55 pounds each.

[3] Estimated data in parentheses.

[4] Some produced but no published statistical data.

[5] St. Kitts and Nevis.

[6] Includes the 16 provinces formerly known as "Free China."

[7] Includes the states of Rio Grande do Sul and Santa Catharina.

[8] Includes Dahomey, French Sudan, Ivory Coast, Muritania, and Niger.

[9] Less than 500 acres.

consumption are probably somewhat misleading because the extent of local production and local consumption is not known.

A study of the Table raises some questions concerning the absence of certain countries from the list. Since the sweetpotato gives high yields of a palatable and highly nutritious food one would expect it to be grown more extensively than it is in certain warm countries. There is probably some good reason why practically no sweetpotatoes are grown in Italy or India, but one would expect that they could become very useful in the food economy of those and other nations having a climate warm enough to grow them successfully.

In many tropical islands and countries sweetpotatoes are grown in almost every garden patch. They constitute an important part of the food for the family of the grower, but they are dug and eaten as needed without entering into trade or commerce of any kind. The aggregate of such production is probably considerable, but we do not have sufficient information to make even an estimate of the importance of this type of production and consumption.

The sweetpotato is an important food item in a number of the countries of the world. In most countries, however, it does not enter into the food requirements to the extent that grain crops and white potatoes do. Whether or not the sweetpotato will be more extensively grown in the future and become more important as food will depend upon a number of things. Among them is the more extensive use of labor-saving machinery. A very important aspect of the increased use of the sweetpotato as a food is the need for reducing the spoilage of the crop after digging. At present this is very heavy. Improvements in methods of

TABLE 2

NUTRITIVE CONSTITUENTS OF THE SWEETPOTATO AND THE WHITE POTATO

	Water %	Protein %	Fat %	Total carbohydrate %	Fiber %	Sugar %	Starch %	Calories in 100 gms.
Sweetpotato* edible portion raw	68.5	1.8	0.7	27.9	1.0	5.4	20.2	125
White potato* edible portion raw	77.8	2.0	0.1	19.1	0.4	0.9	14.7	85

Accessory Food Constituents of Sweetpotato and White Potato (100-gm. sample) †

	Carotene Vitamin A	Thiamine Vitamin B_1	Riboflavin Vitamin B_2	Niacin	Ascorbic acid Vitamin C	Pantothenic acid	Calcium	Phosphorus	Iron
	I.U.	*I.U.*	*Mg.*	*Mg.*	*I.U.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Sweetpotato edible portion raw	3,500	31	68–70	0.1–1.3	160–406	1.0–1.2	19	45	0.92
White potato edible portion raw	30	62	45–55	0.4–2.0	140–300	0.65	14	58	0.85

* As given by Chatfield, Charlotte, and Georgian Adams, 1940 Proximate Composition of Am. Food Materials. U. S. D. A. Circular 549, 91 pp.

† R. W. Pilcher, Ed. 1943, The Canned Food Ref. Manual. 2nd Ed., 552 p. Walter H. Eddy 1941. What Are The Vitamins? 247 pp.

storing, shipping and marketing are to be expected as the result of research work now being carried on. The consequent reduction in spoilage will probably result in a lowering of price and this in turn will tend to stimulate consumption.

Certain aspects of the culture of the sweetpotato favor an expansion in production and use of this food product. Very high yields are possible with good culture. Even on light, relatively poor land, by the use of cover crops and the skillful use of mineral fertilizers, as much as 300 bushels per acre may be obtained. This crop will also tolerate more drought than most other crops. It is possible, therefore, to produce much more food or animal feed on light, poor land by growing sweetpotatoes than with a grain crop such as corn.

The high food value of the sweetpotato in comparison with that of the white potato is shown in Table 2. The sweetpotato is one of the richest foods, not only in carbohydrates but also in vitamins and minerals. As feed for farm animals it has considerable possibilities. In feed value three pounds of green sweetpotatoes which contain from 60 to 70 percent moisture are roughly equivalent to one pound of corn. A 200–300 bushel crop of sweetpotatoes per acre would therefore be equivalent to 65 to 100 bushels of corn. Feeding tests have shown that dehydrated sweetpotatoes make a good feed in combination with other materials for all classes of live stock. It rates at about 95 percent of the value of corn and in some cases is equal to corn in feeding value. Dehydrated sweetpotatoes contain approximately 80 to 85 percent carbohydrates and 4 to 5 percent proteins, whereas the best grade of corn contains 70 percent carbohydrates and 9.6 percent proteins[5]. The vines and leaves when dried have high feeding value and are said to compare favorably with alfalfa hay as forage.

A processing plant in a producing center can prepare for human food or for stock feed or for industrial uses, much material that would otherwise be wasted. Enormous quantities of culls that might be processed are dumped every year. Furthermore, a processing plant could use and thus conserve sweetpotatoes that are of good quality at digging time but which are known to have poor keeping quality because of incipient black rot infection, or for other reasons. For the lack of a suitable outlet at digging time, much stock of this kind in now stored, although much of it must be discarded at packing time because of spoilage in storage.

As the high food value of the sweetpotato becomes more generally known and appreciated it will probably be more sought after for human food and as a stock feed. The sweetpotato is high in energy value and also rich in other important and highly prized food attributes, such as roughage, minerals, and vitamins A and C. There are possibilities of greater industrial use, and the manufacture of and commerce in these products will probably be much more extensive in the future than it has been in the past.

[5] Miller, J. C. Sweetpotatoes for food and feed. Sweetpotato Journal 1, No. 1. Aug. 5–9. 1946.

Pectin—*Its Extraction and Utilization**

This cementing substance between the cells of all plants is economically valuable as a jellifying, stabilizing, emulsifying and binding agent, and is extracted for those purposes principally from apple pomace and citrus peels.

C. W. WOODMANSEE

Delaware Agricultural Experiment Station, Newark, Delaware

Nature of Pectin

For many years the word "pectin" has been used in a general sense to designate a group of substances which, in the presence of sugar and a proper degree of acidity, will form the common jellies or jams familiar to everyone. The flavor of jelly or jam, of course, depends upon the fruit or flavor used in its preparation.

As to the origin of pectins, they are a constituent of plants, being found in the middle lamella or intercellular spaces of the plant tissues. It is thought that pectin acts as a cement, interlacing the cellulose of the cell walls. Chemically, pectins are complex carbohydrates which have been found to be comprised primarily of methylated polygalacturonic acids closely associated with arabinose and galactose. These complexes generally occur as a methyl ester but may exist as a free acid or metal salt. The size of the molecule and the arrangement of its constituents are variable, but the properties that pectins exhibit have been well studied.

Pectin substances are generally grouped into three distinct entities termed "protopectin", "pectin" and "pectic acid". Protopectin is the precursor to pectin, being a water-insoluble parent substance which can be changed to pectin by restricted hydrolysis and made soluble by treatment with acid, alkali or enzymes. In nature this change is found to take place during growth or ripening of plant tissues. Pectin, the intermediate group, is a water-soluble polygalacturonic acid of varying methyl ester content. This group may be subdivided into pectinic acids, provided free carboxyl groups are present, and pectinates, when the carboxyl groups are in combination with metallic salts. By means of enzymic or chemical hydrolysis, water-soluble pectins can be converted to insoluble pectic acid which is essentially free from methyl ester groups but whose salts may be either normal or acid pectates. The enzymes capable of accomplishing these changes are protopectinase, which acts on protopectin and converts it to pectin; pectase, which changes pectin to pectic acid; and pectinase, which has the ability to convert pectin and pectic acid to their simplest cleavage products, presumably galacturonic acid, galactose and arabinose. In the early stages of ripening of fruits, with apple as an example, no soluble pectin is found, but as the fruit ripens the pectin gradually changes to the soluble state until finally, when the fruit is over-ripe, the pectin content decreases along with the solubility. These changes may be retarded by lowering the temperature; consequently, the reason for refrigeration of fruit is quite apparent.

* Published as Miscellaneous Paper No. 32, with the approval of the Director, of the Delaware Agricultural Experiment Station, contribution of the Department of Chemistry. August 25, 1947.

Sources

Pectin is found to some extent in practically all fruits and vegetables. The principal commercial sources, however, are apple pomace and citrus peels. These waste products afford a cheap source of pectin. Apple pomace contains 1.5 to 2.5 per cent of pectin, lemon pulp 2.5 to 4.0 per cent, orange pulp 3.5 to 5.5 per cent, and grapefruit waste 3.0 to 4.5 per cent. Most of the original pectin still remains in the pomace, pulp or waste after the fruit juice has been removed by pressing. Ideally, fruits for jelly should contain sufficient pectin and acid to produce a good jelly without addition of these substances. Some fruits contain enough pectin and acid to accomplish this, while others are deficient in one or both of these substances. For example, crab apples, currants, lemons, limes, grapefruit, cranberries and sour varieties of oranges are fruits rich in pectin and acid. On the other hand, fruits low in both pectin and acid are ripe peaches, Bartlett pears and apricots. When a deficiency of these substances is known it is customary to supplement them by using commercial pectin and citrus juice in the home. The introduction of commercial pectin has eliminated the possibility of a poor jelly in the home and has made possible the standardization of jelly-making in industry.

Preparation

The preparation of commercial pectin from apple pomace and citrus peels involves several step-wise treatments. The particular treatment used depends upon the nature of the raw material and the use to be made of the product. In general, the raw material is subjected to a controlled extraction by means of mild acid hydrolysis in water solution in order to convert the insoluble pectin to water-soluble pectin. Much of the pectin in pomace and peel is in the form of an insoluble alkaline-earth salt of pectinic acid; therefore, polyphosphates render a valuable aid in its extraction. The temperature, time and degree of acidity during the extraction should be carefully controlled in order to obtain the best yield and quality of pectin. The next step is to clarify the pectin liquor, which may consist of treatment with starch-hydrolyzing enzymes, decolorizing carbon and filtration with the aid of various filter-aids. Precipitation of the pectin follows the clarification. This is accomplished either by the addition of alcohol, after partial concentration *in vacuo,* or precipitation of the pectin in dilute solution by colloidal aluminum hydroxide. The success of the alcohol precipitation depends on the completeness with which the alcohol can be recovered, while with the aluminum hydroxide precipitation, the material has to be further treated with acidified alcohol in order to remove the aluminum salts. Drying, grinding and standardization of the pectin follow the precipitation. In the case of commercial liquid-pectin solutions, the pectin extract after clarification is concentrated and standardized as to quality, quantity and acid content of the pectin. Some manufacturers dry the pectin solution in a thin film on a drum or spray dry. In any case, the final pectin product, whether liquid or powder, is usually sold according to grade which is the number of pounds of cane sugar that one pound of pectin can support in a jelly of 65 per cent soluble solids content at optimum acidity.

During the late thirties the scientific literature on the subject of pectic substances began to mention more than one kind of pectin, namely low-methoxyl pectinates and high-methoxyl pectinates. This terminology was based upon the degree of de-esterification or methoxyl content of the pectin, which may range from 0–16.32 per cent, the upper 3 per cent being theoretically possible. The

arbitrary upper limit for low-methoxyl pectinates is 7 per cent; all pectinates above this value are considered to be the high-methoxyl products. Until this time the pectin compounds of commercial concerns were the high-methoxyl pectinates. With the introduction of the low-methoxyl pectinates, gels with low soluble solids content, that is, jellied products with little or no sugar, could be made which were suitable for desserts and salads. Only sufficient sugar for flavoring purposes needs to be added. The preparation of these low-methoxyl pectin gels was found to be slightly more complex than the conventional 65 per cent soluble solids jellies. In addition to pectin, sugar and acid being present, as in regular jelly, it was found necessary to have a polyvalent chemical element present in order to produce gelation. In most cases a calcium salt has been found quite satisfactory for this purpose.

The preparation of low-methoxyl pectinates may be accomplished by three quite different methods. One method results from a high-acid treatment of the pectin over a long period of time at a relatively low temperature. The second method has been to utilize enzymes in order to accomplish the necessary de-esterification, and the third method, to employ an alkaline medium under controlled conditions. All methods have their advantages and disadvantages, but the pectin prepared in any one of the three ways exhibits primarily the same properties. Perhaps the most outstanding characteristic between the low-solids gels and regular high-solids jellies is the superior flavor of the former which is due to the lack of excess sweetness which possibly masks the real fruit flavor in the high-solids jellies.

Uses

By far the greatest use for pectin is in jellies, jams and marmalades, although there are many other uses, some not commonly known. The use of pectin in many food products, cosmetics, pharmaceuticals, medicines, textiles, adhesives, rubber latex, and in the hardening of steel has resulted from research over a period of several years. These are not all the uses, by any means, but perhaps the most important.

In considering the food products that utilize pectin, the original gum-drop, which was prepared with gum arabic and was gummy, chewy and tough, has a competitor using pectin that is more tender, sweeter and brighter in color and which is more closely akin to a jelly than a gum. Pectin is effective as a stabilizer for ices, sherbets and ice cream. Its use as a thickening agent for soda-fountain syrups and crushed frnit has become quite common. In ices it aids to prevent the freezing of water which causes the granulation and crystallization inhibiting the material from freezing smoothly and evenly. In fruit juices it not only thickens but acts as a stabilizer to assist in preventing separation of the pulp. When added to tomato juice or tomato catsup it makes them more viscous and improves the general appearance. It assists in stabilizing and emulsifying salad dressing. In dairy products pectin assists in preventing a heavy curd in milk by acting as an emulsifier and a thickener, while in cheese it preserves the texture during heating to kill certain organisms that may cause deterioration. In bakery products pectin improves the texture, yield and moisture-holding capacity, thereby tending to slow down the staling process.

Many uses have been suggested for pectin in cosmetics and pharmaceuticals. In most cases it serves as a jellifier, emulsifier or binder. It has been employed in dentifrices, salves, pastes, emulsions, cosmetic creams, lotions and as a binder in tablets or pills. Whenever

used it must be under neutral or slightly acid conditions because it is decomposed by alkali.

In connection with the medicinal use of pectin, it has been employed in the treatment of diarrhea and constipation. The particular action of pectin in the treatment of diarrhea is thought to be due to the galacturonic acid of the pectin molecule combining with the toxic substances to aid in their removal. In constipation pectin is useful probably because of its emulsifying and water-holding ability. Pectin is claimed to have antihemorrhagic properties, perhaps due to the galacturonic acid ester of the pectin molecule aiding blood coagulation. One of the most recently reported uses of pectin has been in the treatment of burns and soft tissue wounds. No positive explanation has been made to explain its action, but it does speed up healing when used in the form of pastes or salves. Bacteriologically pectin has been used with excellent results in culture media and found suitable for use in removing inactive proteins during the preparation of antitoxins.

For finishing textiles pectin has been found to be a competitor of starch. The pectin treatment is claimed to be simpler and does not require the auxiliary substances which are generally used along with starch.

Pectin has been found to be a good adhesive which is effective on wood, glass or tin. A preservative is usually used in its preparation. A two to three per cent solution may be used for tipping the end of cigars; however, for a stronger adhesive, the amount in solution should be increased.

The so-called "creaming" of crude rubber latex is covered by patents that recommend the use of pectin. The addition of pectin causes the latex to separate into two layers, which results from the coating of the rubber particle with pectin followed by an equilibrium upset due to a specific gravity difference. Thus the rubber particle is separated from the non-rubber constituents.

Since the heat conductivity of pectin solutions is approximately the same as that of oils used for quench hardening of steel, it has been claimed that varying degrees of hardness may be imparted to steel by simply varying the pectin concentration. A low pectin concentration produces a brittle steel, while a high concentration of pectin produces a hard, tough product. A pectin in water solution of 0.5 to 4.0 per cent has been found a satisfactory range.

With continued progress in science being made day by day through chemical research, it is only natural to expect that the list of uses for pectin will be expanded. Since commercial pectin is a by-product of the fruit industry, its cost of manufacture will be the limiting factor for competing with other products. Even at the present time apple pectin is not so plentiful as citrus pectin, due mainly to competition with the expanding citrus industry on the West Coast. Consequently, as time goes on, we may expect an increase in by-product waste materials, simpler methods of extraction and improved yields, so that the potential uses of pectin can be expanded.

Temperate–Zone Plants in the Tropics

The success or failure of temperate-zone plants transferred to the tropics—blackberry, Boysenberry, corn, grape, plum, raspberry, tomato, Youngberry and others have been tried—is controlled not only by disease, humidity and temperature, but also (in many cases) by the shorter day-length and absence of cold-dormancy there.

JOSEPH L. FENNELL

Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica

Introduction

FROM the viewpoint of the temperate zones, agriculture in the tropics may appear radically different and apart from that of the cooler latitudes. In certain respects this is so, though not to the degree that might popularly be supposed. Actually results show a surprising and deep-seated interdependence between the agricultures of temperate and torrid regions.

The circumstances that limit crop production whether in North America, Europe or Asia, are not of significance only to those regions. A tomato or a bean, for example, that will resist humidity and disease in the tropics may prove of economic value throughout the world. For best progress in agriculture it is essential that we consider crop problems in a universal manner. It is only a few important crops that we can confine our interests strictly to the temperate or to the tropic zone. Such climatic differences in the final analysis reduce to little more than a combination of the variables heat, light and humidity, most of which can be, and often are, experienced in any one environment.

In this view, a cultural or pathological problem—let us say of potatoes, cotton or beans in South America—or, better still, a resistant selection of probable economic or scientific value cannot be limited in importance by geography or climate. The value to humanity is about the only real determinator.

The phenomena associated with reaction of temperate climate plants to tropical environments are matters of broad economic importance. To large sections of the world they have a direct bearing on nutrition and human welfare, since for many cool-climate food crops there are no acceptable substitutes that show good or better adaptability to torrid conditions. To understand the natural influences that lead to success or failure would be to make a full step forward in the over-all problem.

In analyzing the reaction of plants, when placed under any different environment, five fundamental influences should be considered: temperature; duration and intensity of light; humidity; diseases and insects; and soil. These singly or in combination control the crops' adaptability. Furthermore, it makes little difference whether we are considering garden vegetables, field crops, or even such woody perennials as the tung-oil tree, plums, apples or grapes. It is their response to these five influences that will determine the ultimate degree of success or failure.

Before we consider the matter in more detail it might be well to draw a clear distinction between annual and woody

perennial plants. The environmental problems of each must be considered apart. The former are concerned only with circumstances that influence the growing period, while the latter have all of this in addition to a sensitive and most important dormant season to be acted upon. With such perennials usually it is this rest period that proves to be the most deciding factor.

Seasonal Influences

During the growing season, whether with annuals or perennials, results indicate that the most controlling limitations imposed upon temperate climate plants in tropical regions are, broadly speaking, in approximately this relative order: diseases and insects; short light (day) periods of usually high intensity; excess or insufficient moisture; and, of course, in some cases, above-optimum temperatures.

By contrast, with woody perennials the important circumstance of the dormant season is largely a matter of temperature. Practically all temperate plants, by reason of their nativity to regions with cold winters, have what is generally termed a "chilling requirement", that is to say, a certain amount of exposure to low winter temperature, usually 40° F. or below, which is required as an aid to the physiological processes that must precede the beginning of new spring growth. Without this, various signs of poor adaptability are manifest, as will be seen in more detail further on.

The question of whether the species is native to a humid or arid climate likewise is of importance. When types indigenous to dry regions are planted in rainy or humid sections results are apt to be no more favorable than if in the reverse case. We have ample proof of this through the innumerable vain attempts to grow the European grape in humid, southern United States, or the fiasco of the date palm when planted in the humid tropics.

Still another distinction should be observed within the group of tropical plants. Species from medium and high altitudes constitute a classification somewhat distinct from both the lowland tropical and the purely temperate. Several of the annuals or non-woody perennials of this group are among our most important economic crops, as the tomato and potato. When grown as annuals, selected forms of these prosper in the temperate zone summers where growing conditions approximate that of their high altitude native habitat. On the other hand, if they are planted farther down the mountain in the tropical lowlands serious cultural problems often arise. The slight changes in temperatures often alter such climatic matters as rainfall, air humidity and, less directly, disease and insect attacks and even soil fertility. The entire ecology is changed.

Varied Response of Annual Crops

The tomato affords a good example of an economically important plant that gives varied response to seemingly slight differences in environment. Despite the fact that it is of tropical (medium high altitude) origin, it has proven to be one of the most needed and difficult food plants to produce throughout the lowland tropics. The reasons are not simple, as will be seen.

Recently the author had the opportunity to inspect tomato plantings through a large part of the Republic of Venezuela where, incidentally, production problems are unusually severe. The same well-known northern varieties were planted in all locations. In the environs of Caracas (300,000 population) production has been unusually difficult, due principally to attacks of mildew, *Phytophthora infestans*. When we check the prevailing temperatures and humidity and compare these with our own results in the moist highlands of Costa Rica, or with the recently hard-hit tomato-growing sec-

tions of northeastern United States, a significant variety-climate correlation begins to take form.

In regions having roughly the same humidity and seasonal effects—but at some 2,000 feet lower elevation and con-

FIG. 1 (*Upper left*). A new semi-dwarf grain sorghum developed for warm humid climates.

FIG. 2 (*Upper right*). The first horticultural grape known to be derived from a wild tropical species (*Vitis tiliaefolia* × *V. vinifera*).

FIG. 3 (*Center left*). Abundance plum in June in Costa Rica, three and one-half years after planting. Note the sparse foliage and near dormancy, though picture was made in middle of growing season.

FIG. 4 (*Center right*). ***Prunus umbellata***, a wild plum from southern Florida, in June at Turrialba, Costa Rica, three and one-half years after planting. Note the good foliage and normal growth.

FIG. 5 (*Lower left*). A wild "cherry" tomato having relatively good resistance to late blight (*Phytophthora infestans*), and mature fruit (in hand) of its F_1 hybrid with a large-fruited commercial type.

FIG. 6 (*Lower right*). The Turrialba variety, a new tomato developed to better withstand humid and warm growing conditions.

sequently with higher temperatures—an entirely different situation was observed. At the Pampanito Experiment Station, near Trujillo, Venezuela, tomato plantings were being destroyed by nail-head "rust" (*Alternaria solani*). No evidence of mildew could be found.

In other parts of the country where temperature may have been high or relative humidity too low for either of these problems, certain virus diseases were the important limitation. In still other localities, soil-carried organisms, as the various wilts, were serious.

When we compare these observations with results in other tropical or temperate regions where the limitations may be due to any of these difficulties or to leaf mold (*Cladosporium*), leaf spot (*Septoria*), various fruit rots, flower drop or poor growth, the power of climate over variety becomes apparent. Moreover, it is something that can not be overlooked if success is expected.

It will have been noted, no doubt, that no consideration was given to the affects of day length (photoperiodism) in these tomato experiments. Though there is some slight indication that photoperiodic requirements may vary as between northern developed varieties and tropical sorts, this scarcely could be viewed as a major consideration in the present case, since latitude differed little and varieties planted were the same.

When strictly temperate climate vegetables—as the onion or northern sweetcorn—were planted in tropical Costa Rica, a marked demonstration of the effects of photoperiodism was evident. The relatively short days of this near equitorial location typically kept the onion in a state of continuous vegetative growth during most of the year which usually prevented formation of sizable bulbs. This situation has been reported by other workers in various sections of the tropics. In our Costa Rica experiments, only during the period of longest day lengths, May to July, was any appreciable proportion of bulbs formed by most varieties. During other seasons a slowly debilitating foliage growth was continuous.

The action of day length on the northern corn varieties gave quite the opposite affect. In this case, the relatively short day periods reduced vegetative action, usually bringing the plant into tassel at from one to three feet in height.

Indications are that many northern climate perennial plants may in similar manner be seriously restricted in growth or, on the other hand, be stimulated into excessive or prolonged vegetative action, as was the onion.

When we inspect the effect of short day lengths on the sweetpotato in the tropics, as compared to that of longer ones in the central United States, we see beneficial results. Generally with a given variety more tubers are produced in comparison to vine growth in tropical latitudes, and sugar content is apt to be higher. This is understandable, since the sweetpotato is of tropical origin.

Conversely indications are that relatively shorter tropical day periods may restrict sugar development in certain temperate climate plants, as garden beets, strawberries and northern bush or tree fruits. These kinds in general are less sweet to the taste in the tropics than when grown in higher latitudes, irrespective of temperatures or humidity.

Excess rainfall has led to other problems with such warm climate plants as sorghums and peanuts. Most United States varieties of sorghum that we have tested in Costa Rica, especially those with compact heads, were seriously attacked by molds and rots, and the seeds sprouted in the head before harvest if grown during the rainy season. Peanuts, likewise, frequently sprouted before the harvest if caught in a period of very rainy weather.

Plight of Temperate Woody Perennials

The plum, the grape and the blackberry offer good examples of woody temperate climate plants that time and again have been tested experimentally in the torrid zone. The fact that they have almost consistently failed affords some interesting sidelights on the subject. The reasons for these failures, in a broader sense, might be attributed to something in the following relative order: *a*) insufficient cold or chill during the dormant period; *b*) diseases during growing period; *c*) relatively short tropical day lengths. In the final analysis the lack of a cold dormant season would seem to be the one most overpowering influence that prevents satisfactory production of most temperate climate woody perennials in the lowland tropics.

With a few warm-temperate species—those that are indigenous to somewhat intermediate latitudes and dry climates, as the fig, the olive and the European grape—diseases may prove a greater limitation than lack of winter chill. It might be stated more clearly this way: with woody plants native to cold temperate climates, winter chill is the most dominating influence for success. Without this they are worthless. With species native to the dryer and warmer temperate countries, diseases may prove an equal or even greater limitation than lack of dormant-chill.

It might be desirable to view in some detail the results shown by a few actual experiments. When good nursery stock of the Abundance plum, a Japanese variety, was planted at Turrialba, Costa Rica, the first season's growth was unusually vigorous. By October the trees had grown to a height of eight or nine feet, having made unusually long and vigorous switches, well supplied with healthy foliage. By December they were yet lush with tender growth and many leaves, while, by contrast, nearby plants of a wild sub-tropical species (*Prunus umbellata*) from southern Florida were then practically leafless in a natural dormancy.

By the following April the wild Florida plum was again verdant with new spring foliage, though the more northern Japanese variety continued with its leaves of the previous season and by then was showing definite signs of fatigue.

By the following January, two years after planting, the wild Florida plum was once more leafless in a more or less normal dormant period. The Japanese cultivated sort by this time had become obviously sick.

Within three years from time of planting the Abundance variety was in an exhausted state of health, mostly dormant though partly verdant, during all seasons; there was no appreciable difference in growth stage, winter or summer. Limbs or switches, once leafless, failed to put forth new growths or new leaves. Vigorous new growths came only from near the crown, or ground level, giving evidence of a starved or otherwise growth-inhibiting condition of upper plant parts. This is a situation commonly seen with temperate climate woody plants in the tropics and one that mostly can be taken to indicate insufficient chilling and consequent poor adaptability.

The wild Florida species had become completely leafless by December. From January to March a profusion of flowers was produced, and by April the plants were covered with a new cloak of leaves. No water sprouts had grown from lower regions. As compared to scarcely a 15% adaptability for the more northern cultivated variety, this wild southern species indicated no less than 85% adaptability to lowland tropical conditions.

When the North American cultivated grapes, as Concord, Caco, Champion,

Lutie and Niagara, were planted at Turrialba, Costa Rica, growth typically was arrested by premature or mid-summer dormancy. The same need for winter chilling, as seen with the cultivated plum, was evident here. There was the same tendency for production of basal water sprouts and failure of upper plant parts to bud out after once becoming fully dormant.

Three years from planting, these temperate climate cultivated varieties at Turrialba were puny and sick. From a total of 46 plants in 12 varieties, European and American, only two had produced fruit. This was small in quantity and poor in quality.

In the same vineyard wild vines of identical age from Central America and southern Florida, together with improved hybrids of these, grew in full luxuriance, often producing as many as 50 or more fruit clusters. Also these native tropical kinds usually showed a more nearly normal sweetness of fruit.

Experiments with raspberries and blackberries have given interesting results. In a mixed planting of tropical wild kinds and temperate cultivated sorts at Turrialba, Costa Rica, the need for winter chill with the northern varieties was evident.

The Latham red raspberry, after making moderately good growth the first year, failed to bud out the following spring from fully dormant canes—all good growths coming from near the crown, as was the case with the northern plums and grapes. After two years of steadily decreasing vigor, all plants of this variety were dead. Three black-cap varieties gave nearly similar results, though persisted a few years longer.

The popular Boysenberry and Youngberry of the southern United States, after making each year luxuriant and relatively disease-free growth, failed to bud out in the spring from upper buds of mature canes, thus giving no flowers or fruit.

In contrast to these poor results with the temperate varieties, several medium elevation tropical species, *e.g.*, *Rubus trichomallus* and *R. rosiaefolius*, though in some cases much more attacked by disease, gave heavy fruit crops under identical cultural conditions.

Still different reactions were observed with the tropical high-elevation raspberry *R. glaucus* and the subtropical lowland dewberry *R. okeechobeus*, neither of which indicated need for dormant chill nor longer day lengths. During average years both species made excessive vegetative growth, though they produced few flowers. When the seasons were unnaturally dry, the *okeechobee* dewberry flowered heavily.

Observations lead to the belief that meager fruit production obtained from these latter kinds was due in large part to growth conditions being overly favorable. In their native habitats this excess growth is prevented by cool temperatures with the highland raspberry and by poor soil and droughty conditions with the lowland dewberry. Lacking these controls both species tend to over indulge in riotous vegetative living.

Climate-Variety Correlation Importance

All too frequently there is the tendency to ignore, or at least to underestimate, the importance of climate in tropical agriculture. The frequent and almost indiscriminate "hopeful" planting of cold climate perennial varieties in tropical regions gives evidence of this. In the reverse case it would be scarcely conceivable that anyone would expect success from banana, mango, pineapple or any of the torrid zone crops if planted out of doors on the colder side of latitude forty. Presumably no one would so much as try it. By what right then should we expect favorable results when plants, native to these colder regions, are brought to the tropics.

In agriculture, whether in the colder

sections or on the equator, it is seen that the most powerful influence controlling the end result is the combination of temperature, humidity and light we popularly term climate. Even soil fertility, disease and insect attacks—in part at least—are a result of this influence. For best success a crop variety should be correlated closely in respect to cultural requirements with these forces. That is to say, it should have whatever genetic characteristics are necessary for it to prosper under the environmental conditions imposed. Whenever we have chosen to lunge forth without heed to these matters, disappointment has been the unfailing result.

In making a variety-climate correlation a few most important points of determination might be these: *a*) does the variety require a winter or dormant-season chill and, if so, can the environment in question satisfy this need; *b*) is the variety suited to the prevailing temperatures for the growing season; *c*) is the humidity and rainfall ample or excessive for the variety; if excessive, will it resist the diseases or prosper in the soil as influenced by such conditions; *d*) is the variety adapted to the day lengths or light periods of the latitude in question, or the amount and strength of sunlight, as determined by more localized conditions; *e*) is it equal to whatever other natural circumstances or limitations of region might influence success.

No doubt a few of these questions might best be answered through actual trial, though, for the majority, there is need for little more than a comparison of the climates of the proposed and native environments.

One of the first questions popularly asked when temperate climate plants fail in the tropics is: what about the soil or the cultural practices? Seldom have we inquired of the climate, or of the plants' adaptability to it.

Soil and cultural practices are important, of course, though usually in a secondary way to the more fundamental matter of climatic adaptability. Lacking this, it is mostly a losing fight, irrespective of all other modifying circumstances.

Improvement Possible with Proper Approach

To peoples of the tropics the prospects would appear discouraging for many desired and much needed food plants were it not for the well demonstrated science of genetics and plant breeding. Through this and with a methodical approach, almost any desired end is possible. Nevertheless we often are compelled to expend greater immediate labors than was the case for crop improvement in the temperate zones. Our end results, however, may come faster.

When better apples, grapes, wheat or cabbages were desired in Europe or North America the important considerations mostly were for better quality, higher production or disease resistance. Ofttimes relatively minor variables of climate were considered, though, since all parent material was native to medium or higher latitudes with cool or cold winters—there was no problem of harmonizing radically different factors of climatic adaptability. More complex is our problem in the tropics.

In any outline for a new and better crop variety for warm climate production, generally speaking, stronger resistance to diseases and insects, as well as to extremes of drought, moisture and heat, must be considered. If we are compelled to inter-breed temperate with tropical kinds, these problems are multiplied severalfold. In the progeny selection consideration to more factors must be given, and of course the percentage of good to bad in the hybrid populations will be much smaller.

In this way immediate gains might appear to come more slowly, though we have the advantage of availability to the improvement program of certain plant genes for superior quality; varieties brought to their present high development through the many years of tedious progress in temperate agriculture. When these factors for superior quality are combined with others native to the tropics for better adaptability, considerable improvement can be expected in tropical agriculture. Relatively speaking, this is a field just beginning to unfold.

Value to Temperate and Tropical Regions

In agriculture the world over there is the tendency for over-specialization at the expense of broader interpretations. Great emphasis and study often have been placed on some detailed and localized problem which allowed proportionately little thought for the wider ramifications it might have with distant plant relationships and climates. With this strict and even short-sighted approach we may struggle over some question of plant culture or improvement, wherein if with a more universal understanding, even at the expense of some degree of specialization, the problem might be vastly simplified. In short, the end progress would most assuredly be greater.

Throughout the years plant science has labored in great detail and at much expense to acclimatize or to control disease on many important crops. Well and good, but had a due proportion of this effort been devoted toward comprehending and charting the vast world reservoir of already acclimatized and disease-resistant breeding material many short-cuts and perhaps more rapid progress might have been possible. The admirable work of Reddick in giving blight resistance to the common potato from an obscure related species wild in Central America is an example of this.

It is understandable, of course, that no one research worker, in the temperate zone or in the tropics, can be expected to know the full potentialities of useful plant breeding material throughout the world. The job is far too tremendous for any one individual. What is needed and would seem to be feasible is a better coordination and interchange of knowledge and appreciation of connected problems on the part of plant research workers everywhere. A closer tie-up between the temperate zones and the tropics is an especial need.

Plant improvement in the tropics can have pronounced value to temperate crop production. From certain viewpoints these warmer regions might be looked upon as an outdoor workshop where genetic, pathological and physiological problems can be studied more effectively and where all year growing conditions often allow a saving of more than half the costly time requirement in long term breeding programs. When well developed and closely synchronized with its temperate zone equivalent, plant research in the tropics undoubtedly will become of vast significance to worldwide agriculture.

Plant Breeding Methods and Current Problems in Developing Improved Varieties of Tomatoes[1]

An even greater use of the tomato as a food plant than at present may be possible through the breeding of more productive varieties having higher nutritive value and vitamin-C content. Such varieties might be developed by incorporating in the cultigen, Lycopersicon esculentum, certain desirable genes found in closely related species. For this purpose further genetic studies are necessary, and the development of suitable plant-breeding methods.

J. W. LESLEY[2]

University of California Citrus Experiment Station, Riverside, California

Introduction

PERHAPS the two most important advances in plant breeding methods in the past 25 years have been the development of the backcross method, which has been used so effectively in breeding cereals and in genetic studies with tobacco, and the use of hybrid seed from the crossing of inbred lines. Statistical methods of measuring quantitative characters, embryo culture for effecting difficult crosses, and artificial inoculation in testing disease resistance have also found wide and useful application.

Much remains to be learned about methods of plant breeding, especially in dealing with quantitative characters and in species hybridization. Harlan, Martini and Stevens (4) have directed attention to the need for experimental studies in plant breeding. In an investigation of barley breeding methods, they found barley crosses in a composite mixture apparently as effective as pedigree cultures from the same crosses in developing a high-yielding population. Goulden (3) has suggested a novel method of breeding desirable homozygous new combinations in cereals, namely, the production of as many homozygous lines as possible by growing very small test progenies in rapid succession outdoors or indoors, and then extensive agronomic tests for yield and other desirable characters, using modern statistical methods for measuring quantitative characters.

Mather's (10) studies of polygenes which determine quantitative characters indicate that the fixation of characters through inbreeding may easily result in the total elimination of desirable polygenes or multiple genes. Inbreeding, especially selfing, may lead to the fixation in many individuals of undesired alleles, with the result that the desired recombination cannot occur. Unsuccessful attempts to combine desirable characteristics in new varieties may therefore result from premature fixation of genes caused by selfing. The desired combination of polygenes frequently is obtainable only through crossing-over in heterozygotes, and only in this event would the desired combination, in one chromosome, of important genes favoring the desired phenotype occur. Evidently, for selection, especially if linkage is close, it is necessary to have a large population of plants that

[1] Paper No. 574, University of California Citrus Experiment Station, Riverside, California.

[2] Associate Geneticist in the California Agricultural Experiment Station.

are heterozygous for the polygenes which, alone, may have similar and relatively inconspicuous effects, but in combination produce the desired genotype. Presumably, if some practicable treatment could be applied to increase the amount of crossing-over, a smaller population would suffice.

Without knowing fairly clearly the genetic basis of the character desired, it is unwise to select a few F_2 plants and to continue selection in F_3 and succeeding generations in the expectation that the desired combination will appear in homozygous form. In the first place some important polygenes may be eliminated by selection in F_2 because they happen to be combined with some undesired character. It may be advisable to postpone selection and to raise a large number of small F_3 families, and then, in selection, not to favor necessarily the more homogeneous F_3 families. If it is suspected that through faulty selection too much fixation of genes has occurred in F_3, or even later, it may be necessary to cross selected plants in different families, in the expectation of obtaining the desired recombination.

Without doubt many of the characters important in tomato breeding depend on multiple genes. This applies to such characters as fruit size, fruit shape, number of loculi, and time of maturity of fruit.

Another important character, especially in regions having high temperatures, is the ability of the plant to set fruit, as indicated by the proportion of flowers that form fruit instead of undergoing abscission. Experiments by Went (19) with controlled temperature, humidity and light show that the temperature during darkness greatly influences fruitfulness, and that varieties differ greatly in their response to environmental conditions. In the field at Riverside, California, it has been noted that the varieties Santa Clara and Oxheart bloom freely, but in most years set little or no fruit until late summer, whereas First Early and Pearson regularly set fruit well.

Certain combinations of genes are no doubt favorable to fruit setting under prevailing climatic conditions. One mutant gene that seems to be associated with fruitfulness during a limited period is *sp* (self-pruning) which J. W. MacArthur found to be in chromosome 4, only 3.7 units from *c*, the gene for potato leaf. The determinate growth caused by *sp* seems to favor fruitfulness. Such self-pruning or determinate varieties as Bounty, Pennheart, Pearson and Pearl Harbor, for example, tend to bear very heavily for a limited period beginning with the first bloom.

The self-pruning plant has, on the average, only about 1.5 nodes between successive inflorescences (Fig. 1), which is one half of the normal number. The nearly continual supply of flowers ready for fertilization on a self-pruning plant may tend to offset the effect of occasional spells of weather unfavorable for fruit setting, and so increase fruitfulness. The presence of three nodes between inflorescences in the Simi variety (Fig. 4), which is semi-determinate in growth, may be due to a gene similar to *s* (compound inflorescence), which increases the number of nodes. Yield of fruit may be influenced less by the number of flowers per inflorescence, which may be as low as one or two, than by the number of inflorescences.

Single-Plant Selection

The cultigen *Lycopersicon esculentum* Mill. is predominantly self-fertilizing. The amount of crossing depends on the variety and the climatic conditions under which the plants are grown. Estimates by Currence (2), with plants having 6×6 foot spacing at St. Paul, Minnesota, range from about 1.6% to 5.2%. A tomato field grown from seed of superior purity

FIG. 1 (*Upper left*). This *sp sp* (self-pruning or determinate) hybrid plant obtained after three generations of backcrossing and two of selfing from *Lycopersicon esculentum*, *L. pimpinellifolium* and *L. hirsutum* shows the low average number of nodes between inflorescences (about 1.5) associated with high yield.

FIG. 2 (*Upper right*). Shoot of vigorous tobacco mosaic-tolerant plant obtained from selfing a parent from the second backcross generation of (*L. esculentum* × *L. hirsutum*) × *L. esculentum*. This plant produced a good but late-maturing crop of red fruits, shown in Fig. 5.

FIG. 3 (*Lower left*). Shoot of Pearson tomato plant (*L. esculentum*) treated with the same tobacco-mosaic inoculum as plant in Fig. 2. Growth was stunted, leaves were mottled and distorted, and crop was reduced.

FIG. 4 (*Lower right*). Simi, a less fruitful variety of *Lycopersicon esculentum* than that shown in Fig. 1, has three nodes between inflores-censes, but is semi-determinate, perhaps because of a gene similar to *s* (compound inflorescence), which increases the number of nodes.

is largely composed of many similar pure lines, a few hybrids from crossing with other varieties, and a very small proportion of mutant forms, such as triploids and gene mutants.

In single-plant selection in tomatoes too much emphasis has perhaps been placed on the desirability of utilizing a single pure line, and on measurements of single plants rather than of their progeny. The tendency in selection in other largely self-fertilizing crops, such as wheat and cotton, is not to utilize a single pure line which confers the maximum genetic fixity, but to isolate a group of superior lines, by measurement, not of single selected plants, but of the progenies of such selected plants. After the necessary number of generations with or without controlled pollination, these lines are mixed to form the new variety. The value of such a variety consists in its plasticity and in the capacity of such a mixture to become adapted to changed environmental conditions of culture, disease and weather. The rapid improvement of Tangüis cotton in Peru by Harland (5) illustrates the superiority of progeny tests over individual plant tests when combined with a thorough knowledge of the type of plant desired and with judicious single-plant selection on a large scale.

Intrasubgeneric Hybridization

Crossing of varieties or species within the subgenus *Eulycopersicon* C. H. Mull., followed by backcrossing or selfing or both, has given rise to most of the new tomato varieties that are useful for planting or as parents. In such crosses a high degree of fertility is the rule, and a large measure of gene recombination certainly occurs. In fact, some geneticists are inclined to regard *Lycopersicon esculentum* and *L. pimpinellifolium* (Jusl.) Mill., of the subgenus *Eulycopersicon*, as a single species. Usually the purpose has been to develop pure lines having a certain combination of genes from the parent varieties.

As in selection without hybridization, the superior plasticity of a variety that is a mixture of genotypes, and its ability to adapt itself to changed conditions, are sometimes desirable. The Pearson tomato, which has proved highly successful in California, is reported to have been released as an F_3 population. White Federation 38, a stem-rust- and bunt-resistant wheat bread by F. N. Briggs (18) was, when released, a composite of 182 F_3 lines from parents which were genetically different in resistance to these diseases and probably in other respects.

Failure to obtain the desired genotype or genotypes is likely to be due to (*a*) the selection of an inadequate number of plants in F_2 and in the first backcross generation (BC1), (*b*) too much reliance on the character of the individual plants rather than of their progenies, and (*c*) failure to make measurements of the progenies of the selected plants. In a detailed report of an attempt to combine two characters of a quantitative nature, namely, fruit size and fruitfulness, only 39 F_2 plants were originally selected on the basis of productivity and fruit size. Careful individual plant records were kept, derived from many pickings. On this very uncertain basis only 6 F_2 plants were finally selected. Large F_3 progenies were grown from these, but none of the 20 F_3 plants selected had the desired combination or even a very close approach to it.

When it is desired to transfer one or two characters which genetic analysis has shown to depend on a few genes, from one variety or subspecies to another containing most of the desired genes, some variation of the backcross method is generally employed. The variety Pan America was obtained by Porte and Walker (12) by crossing Marglobe with a certain race of *L. pimpinellifolium* which is highly resistant to fusarium wilt, backcrossing

to Marglobe for three generations, and subsequently selfing for five generations.

The breeding of desirable early-maturing varieties seems to present special difficulties. Powers and Lyon (13), in an important contribution, showed that the interval from seed-sowing to maturity consists of three stages or periods, each having a distinct genetic basis, namely, the number of days (*a*) from seeding to blooming, (*b*) from blooming to first fruit set, and (*c*) from first fruit set to complete change of color of any fruit. The breeding of an extremely early-maturing variety resistant to fusarium wilt evidently requires the combining of the appropriate genes for the three shortest possible stages of development, with the dominant gene for resistance to fusarium wilt. In an attempt to accomplish this, a very early-maturing variety, First Early, was crossed with Pan America, a late-maturing variety highly resistant to wilt. Selection, in the BC1 generation, of 187 plants from $F_1 \times$ First Early was based solely upon wilt resistance and length of period from sowing to first bloom; all other characters, including fruit size and fruit shape, were ignored, with the idea of growing small progenies from a fairly large number of plants and reducing the chance of eliminating desirable genes for earliness which were linked with these undesirable fruit size and shape characters. Small families were grown from selfing 34 BC1 plants, and it is now proposed to backcross one or two plants in each of these families and grow small families from them, selecting only for wilt resistance and short periods of development. Selection in BC1 for wilt resistance may have resulted in loss of some desirable genes through linkage between genes causing early maturity and susceptibility to *Fusarium*.

In continuous backcrossing and selfing, the proportion of homozygosis for the same number of generations, and the proportions of individuals heterozygous for one, two or more genes, are the same. The number of different homozygous and heterozygous types is greater from selfing. For a three-gene difference in the parents, BC1 contains 7 heterozygous and 1 homozygous type identical with the recurrent parent, whereas F_2 contains 19 heterozygous and 8 homozygous types. In BC2 the proportion of types heterozygous for two pairs of genes in which the P_1 plants differed is the same as in F_3. Even in crosses involving characters that depend on multiple genes, of which the number and interaction are unknown, the probability of obtaining a desired combination of genes may be greater from an appropriate backcross method, including a large BC1 family, provided that most of the genes of the recurrent parent are to be retained.

Intersubgeneric Hybridization

The introduction and distribution by the Division of Plant Exploration and Introduction, U. S. Department of Agriculture, of several species of *Lycopersicon* from South America has greatly increased the scope of tomato breeding. The especial value of these species is a resistance to certain tomato diseases far exceeding that of the cultigen *L. esculentum*, including some virus diseases such as tobacco mosaic, which is in practice difficult to control; some serious fungus diseases such as fusarium wilt; and even root-knot nematode, *Heterodera marioni* (Cornu) Goodey.

A vitamin-C concentration about four times that of the common tomato was found by Reynard and Kanapaux (14) in *L. peruvianum* (L.) Mill. It is possible that through hybridization tomatoes may become an even more important source of ascorbic acid than at present. Other desirable characters such as a more intense red color and greater ability to set fruit under unfavorable soil and climatic conditions may result from species crosses.

All the species of *Lycopersicon* studied have, as a rule, 24 chromosomes in the somatic cells and 12 pairs in the pollen mother cells. *L. cheesmanii* Riley, of which the last recorded collection, according to Muller (11), was by Andersson in 1906, has not been studied. *L. esculentum* is crossed easily, as seed parent, with *L. hirsutum* Humb. and Bonpl. and *L. p. dentatum* Dun., but embryo culture is recommended to cross *L. esculentum* with other races of *L. peruvianum*. MacArthur and Chiasson (9) crossed *L. peruvianum* and *L. glandulosum* C. H. Mull. Generally, the cultigen has been used as female parent on account of the unfruitfulness of several species of the subgenus *Eriopersicon* C. H. Mull. when grown at latitudes ranging from 34° to 45° N., and in Hawaii. In southern California *L. hirsutum* and some races of *L. peruvianum* bloom profusely but rarely set fruit outdoors in summer or indoors in winter. At Riverside, California, *L. p. dentatum* is a weak grower which flowers only at intervals and rarely sets seed. According to Luckwill (7), some *Eriopersicon* species, especially *L. hirsutum*, gave a photoperiodic reaction and set more fruit with an 8-hour day than with a 12-hour day. In its native habitat *L. hirsutum* is a perennial; it is said to be most abundant in the mountains of southern Ecuador. *L. peruvianum* grows in a coastal region that is regularly blanketed during winter with a dense fog and has very little measurable precipitation.

The F_1 intersubgeneric hybrids bloom freely but, like some of the *Eriopersicon* parents, tend to be sterile. The sterility of *L. esculentum-L. p. dentatum* hybrids is subject to seasonal variation. At Riverside a diploid hybrid was practically sterile for five years and then became fairly fertile, but a tetraploid F_1 sib was more fertile.

Meiosis in intersubgeneric F_1 hybrids is usually regular. Twelve bivalents ordinarily occur at first metaphase, leading to normal spore tetrad formation. Occasionally, lagging of one or more chromosomes at the first division occurs, followed by supernumerary spore formation, spore diads and failure of the spores to develop into pollen grains. *L. esculentum* × *L. p. dentatum* and *L. esculentum* × *L. hirsutum* F_1 backcrossed to *L. esculentum* gave some fertile and some sterile plants, but even in sterile plants meiosis was usually regular. It was more irregular in hot weather but still quite regular in some pollen mother cells. Even in *L. esculentum* meiosis is disturbed by extreme temperatures, and when these plants are grown at a constant day temperature of 80° F. and night temperature of 88° F., no pollen mother cells are formed.

Polyploidy is not common enough to constitute a major cause of sterility. Tetraploid F_1 hybrids of *L. esculentum* × *L. p. dentatum* were more fruitful than the corresponding diploid. A simple trisomic 25-chromosome plant occurred in BC1 to *L. esculentum* and was sterile. Polyploidy seems to be even less frequent in hybrids of *L. esculentum* × *L. hirsutum*.

Sterility has been observed in intersubgeneric hybrids in the field and in the greenhouse. As MacArthur and Chiasson (9) point out, this may be due to the same external conditions that cause sterility in the parent species of *Eriopersicon*. Meiotic irregularities which are more frequent in hot weather partly account for the hybrid sterility. The possible role of genic sterility is as yet undetermined.

Although selective elimination of some desirable gene combinations may occur through sterility, since certain plants from intersubgeneric crosses are unfruitful and cannot be reproduced by seed, the regularity of meiosis suggests that recombination of genes occurs even in the widest crosses. The prospects of breed-

ing a good tomato combining the more desirable genes of *L. esculentum* with those of species of *Eriopersicon* are, on the whole, favorable.

What is known of the genetic relation between the species is largely derived from backcrosses, usually with *L. esculentum* because of the male sterility of the F_1 hybrids. Some characters that are inherited in a simple way and are easily distinguished in *L. esculentum* proved to be genetically complex in species crosses. This applies to flesh color of fruit due to lycopene and the various yellow pigments determined by the *Rr* alleles in *L. esculentum*, and to skin color of fruit determined by the *Yy* alleles. The non-yellow skin and non-red flesh of *L. hirsutum* and *L. p. dentatum* were partly dominant over the yellow skin and red flesh of *L. esculentum*, and the BC1 to *L. esculentum* contained a series of intergrades. Despite the gradations in red flesh color occurring in plants of BC1 (*L. esculentum* × *L. p. dentatum*) × *L. esculentum*, types appearing to be identical in redness with *L. esculentum* appeared in BC2.

Similar genetic relations have been found in *Gossypium*. Harland's (6) interpretation is that the species of this genus contain different sets of modifying genes for the character concerned, and that through recombination of these genes new types appear. On this theory many gradations would occur between the parental values, and there is a possibility that as a result of a fortunate combination of modifying genes, genotypes may arise from such a species cross which exceed both parents in grade of some character of economic importance. Lyon (8) reports that, in a cross of two species as closely related as *L. esculentum* and *L. pimpinellifolium*, types occurred in F_2 with a shorter period from first fruit set to first complete color change than that of either parent. One hybrid derived from three species had fruit that was deeper red in flesh color than any of the parents. It is probable that most of the characters which distinguish species belonging to different subgenera of *Lycopersicon* will behave as does red flesh color, including perhaps such characters as high vitamin-C content and resistance to tobacco mosaic and to *Heterodera marioni*. On the other hand, MacArthur and Chiasson (9) report that several recessive mutant genes in *L. esculentum*, which determine differences of a non-specific nature, behave as recessives in intrasubgeneric crosses. Accordingly transfer of a gene such as *sp*, which seems to be associated with fruitfulness, should be comparatively simple. The hybrid of *L. esculentum* × *L. hirsutum* shown in Figure 1 was self-pruning and highly fruitful.

Although the prospect of transferring desirable genes from species of the subgenus *Eriopersicon* to *L. esculentum* is generally favorable, sterility and the probable genetic complexity of the specific differences present formidable problems. When more is known of the cause of the sterility and of the genetic basis of the desired characters, an appropriate system of breeding may be evolved. For the present, some application of the backcross method, using *L. esculentum* as the recurrent parent, is indicated, especially because of the self-sterility of the intersubgeneric hybrids. A plant of the fourth generation of backcrossing the F_1 hybrid *L. esculentum* × *L. p. dentatum* with *L. esculentum* was selfed and produced plants in which, in the opinion of Dr. J. T. Middleton and the writer, the large size, determinate growth and red flesh color of *L. esculentum* are combined with resistance to verticillium wilt derived from *L. p. dentatum* (Fig. 6). A family derived from *L. esculentum* × *L. p. dentatum* by six generations of backcrossing or selfing contained some plants which showed no dwarfing and very slight leaf symptoms when inoculated by Dr.

J. M. Wallace with a virulent strain of tobacco mosaic. The fruitfulness of these plants at Riverside was subnormal, however. Another family derived from *L. esculentum* × *L. hirsutum* by two generations of backcrossing and one of selfing also had only very slight mosaic symptoms, like *L. hirsutum* (Figs. 2 and 3). Some plants produced a fair crop, though somewhat late in the season (Fig. 5).

stages of development from planting to first complete color change in certain crosses studied by Powers and Lyon (13).

Heterosis seems to affect fruit setting; it is therefore especially useful. Suitable varieties may be found, or inbred lines developed, to produce hybrid tomatoes which set more regularly than others, mature earlier and are more resistant to diseases. For this purpose more knowledge of the genetics of resis-

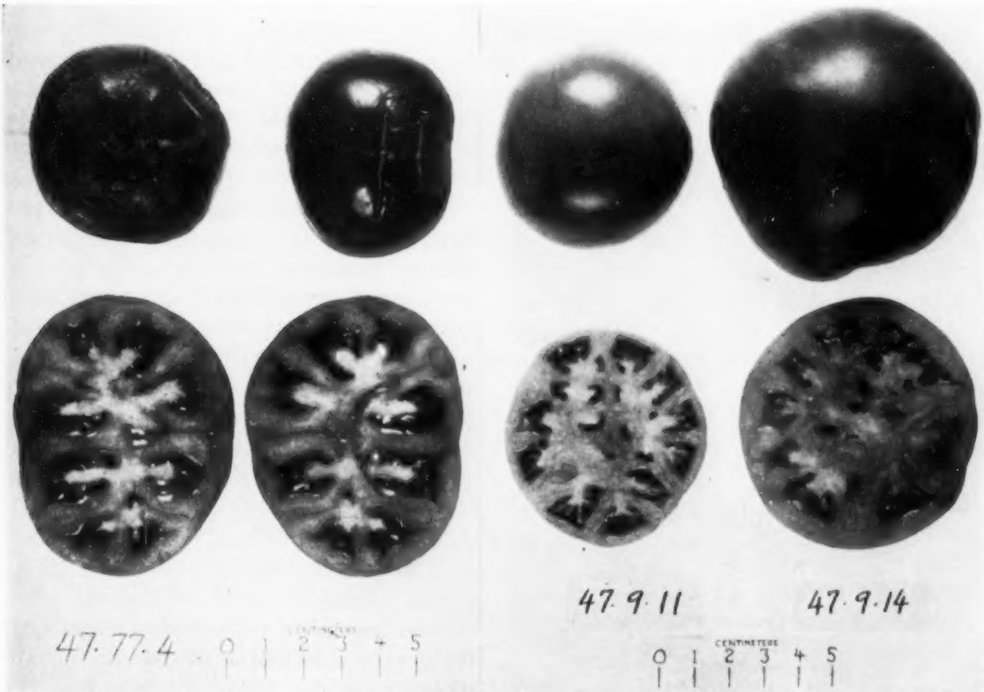


FIG. 5. (*Left*). Fruits of tobacco mosaic-tolerant plant shown in figure 2 obtained by crossing *L. esculentum* and *L. hirsutum* followed by backcrossing for two generations to *L. esculentum* and selfing for one generation.

FIG. 6 (*Right*). Fair-sized multilocular red fruits of two verticillium wilt-resistant plants originally from four generations of backcrossing (*L. esculentum* × *L. peruvianum dentatum*) × *L. esculentum*, followed by selfing.

Hybrid Tomato Seed

The report of hybrid vigor in tomatoes by E. von Tschermak in 1918, and reports of heterosis for other characters by recent workers, led to testing the usefulness of hybrid seed. Heterosis affects time of maturity and causes the F_1 hybrid to ripen earlier than either parent. It was found for one or other of the three tance to diseases is needed. When resistance behaves as a simple dominant, as found by Bohn and Tucker (1) for resistance to fusarium wilt and to *Cladosporium fulvum* in the variety Vetamold, or when it depends on only a few genes, suitable lines may be combined for making resistant hybrid seed.

The discovery by Rick (15) of simple

recessive male sterility will eventually make emasculation unnecessary and promises a far wider use of hybrid seed. By combining genetically distinct male steriles with male fertiles, it should be possible to make multiple hybrids and thus obviate the need of combining all the desirable characters in a single variety. The F_1 hybrid of male-sterile Pearson and male-fertile Pennheart, obtained by Rick (Fig. 7), gave evidence of heterosis in earliness and was more productive of early fruit than the standard commercial variety First Early.

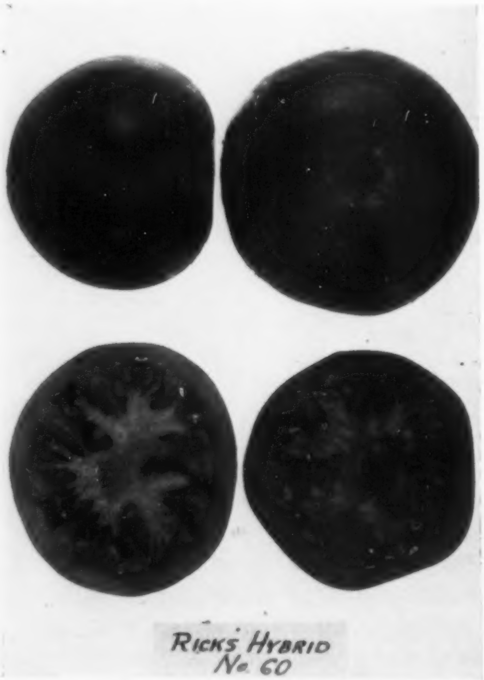


FIG. 7. Fruits of F_1 hybrid obtained by C. M. Rick from crossing male-sterile Pearson with Pennheart. This hybrid shows promise because of its early maturity and high yield of early fruit in May at Indio, California.

Tetraploidy

There is some evidence that tetraploid tomatoes are higher in vitamin C and contain fewer seeds and more dry matter than diploids of the same race. Tetraploids are obtained from adventitious shoots and, as Stair and Showalter (16) found, by the application of colchicine. In *L. esculentum* they rarely occur as seedlings from diploids, but in species crosses they may be more common. Of 100 F_1 plants from *L. esculentum* × *L. p. dentatum*, three were tetraploid; and in F_1 from a diploid plant of the second backcross (*L. esculentum* × *L. p. dentatum*) × *L. esculentum* crossed with another race of *L. peruvianum*, the only plant obtained was tetraploid.

Autotetraploids of *L. esculentum* are usually less fruitful than the corresponding diploids, but some varietal hybrids appear to be nearly as fruitful as the diploids. A similar effect of genetic composition on fruitfulness has been observed in triploid and trisomic types. Homozygous triploids and simple trisomic (25-chromosome) types in the field bore very few fruits, but certain triploid and triplo-I (first-chromosome) hybrids were almost as fruitful as their diploid sibs. Selection for fruitfulness among certain tetraploid hybrids of *L. esculentum* may therefore be worth trying.

The tetraploid F_1 hybrids of *L. esculentum* × *L. hirsutum* developed by MacArthur and Chiasson (9) were not more fertile or more fruitful than the F_1 diploids. One tetraploid F_1 hybrid of *L. esculentum* × *L. p. dentatum* was more fertile and fruitful than the diploid but has been highly variable in these respects, apparently as a result of environmental conditions, particularly the proximity of pollen of the diploid hybrid. Attempts to self this hybrid in the greenhouse produced only seedless fruits for several years. It has been classified as a segmental allopolyploid.

According to Stebbins (17), there is evidence that tetraploid species hybrids in certain respects superior to diploids could be developed by selection and backcrossing. A tetraploid of *L. esculentum* × *L. p. dentatum* was crossed with 4*n* *esculentum*, then selfed for

three generations and again crossed with 4*n* *esculentum*. The resulting family varies considerably in fruitfulness, and some plants are certainly more fruitful than the F_1 tetraploid. It is possible that very fruitful hybrid tetraploids might be obtained by a suitable combination of male-sterile and male-fertile parents.

Tetraploid tomatoes have not, so far, proved to be of economic importance, but the possibility remains that fruitful types may be developed which will have special, desirable properties.

It is conceivable that in some excessively fruitful self-pruning varieties the reduction in fruitfulness of autotetraploidy may actually give a more desirable plant, with more adequate foliage, better fruit and a good yield. The tetraploid form of Pearl Harbor obtained by decapitation may be an example.

Summary

The application to tomato breeding of methods which are in use with other self-fertilizing plants, or which have been proposed by students of breeding methods, are discussed.

A new variety consisting of a mixture of pure lines or an F_3 population may be desirable because of its plasticity.

In intrasubgeneric hybridization the desired recombination of genes may be obtainable only through crossing-over in plants heterozygous for those genes resulting in chromosomes containing the proper combination of genes. Selfing tends to cause fixation of genes in undesirable combinations. Drastic selection, especially in F_2 or BC1, may lead to the unconscious elimination of desirable polygenes and is perhaps better deferred.

Meiosis in the pollen mother cells of intersubgeneric hybrids is fairly regular, but sufficient irregularities may occur, especially in hot weather, to cause male sterility. The sterility found in some parent species as the result of changed environmental conditions may also be found in their progeny. Recombination of genes, even in intersubgeneric hybridization, may be feasible. Specific differences caused by different systems of modifiers may be more difficult to transfer than mutant characters of a nonspecific order, such as the gene *sp* of *Lycopersicon esculentum*.

Hybrid tomato seed shows considerable promise, especially in increasing fruitfulness and earliness of maturity, and should obviate the necessity of combining all the desired characters in a single variety.

Tetraploids, which are now of uncertain economic importance, may eventually through heterosis or by continued selection, become fruitful enough. Excessively fruitful self-pruning diploid varieties may develop more foliage and more and better fruit by becoming tetraploid.

Literature Cited

1. Bohn, G. W. and C. M. Tucker. Studies on fusarium wilt of the tomato. I. Immunity in *Lycopersicon pimpinellifolium* Mill. and its inheritance in hybrids. Missouri Agr. Exp. Sta., Res. Bul. 311. 1940.
2. Currence, T. M. and J. Mitchell Jenkins, Jr., Natural crossing in tomatoes as related to distance and direction. Proc. Am. Soc. Hort. Sci. **41**: 273–276. 1942.
3. Goulden, C. H. Problems in plant selection. VII. Int. Cong. Genet., Proc., Edinburgh, **1939**: 132–133. 1941.
4. Harlan, H. V., M. L. Martini, and H. Stevens. A study of methods in barley breeding. U. S. Dept. Agr., Tech. Bul. **720**. 1940.
5. Harland, S. C. The selection experiment with Peruvian Tangüis cotton. Soc. Nac. Agr. Inst. Cotton Genetics, Lima, Peru, Bul. 1. 1944.
6. Harland, S. C. Genetical studies in the genus *Gossypium* and their relationship to evolutionary and taxonomic problems. VII Int. Cong. Genet. Proc., Edinburgh, **1939**: 138–143. 1941.
7. Luckwill, L. C. The genus *Lycopersicon*. Aberdeen Univ. Studies No. **120**. 1943.
8. Lyon, C. B. Inheritance of stages of earli-

ness in an interspecific cross between *Lycopersicon esculentum* and *L. pimpinellifolium.* Jour. Agr. Res. **63**: 175–182. 1941.

9. MacArthur, J. W., and L. P. Chiasson. Cytogenetic notes on tomato species and hybrids. Genetics **32**: 165–177. 1947.
10. Mather, K. Genetics Department Report. *In:* 37th Ann. Rept. John Innes Hort. Inst., London, **1946**: 12–17. 1947.
11. Muller, C. H. A revision of the genus *Lycopersicon.* U. S. Dept. Agr., Misc. Pub. 382. 1940.
12. Porte, W. S., and H. B. Walker. The Pan America tomato, a new red variety highly resistant to fusarium wilt. U. S. Dept. Agr., Cir. 611. 1941.
13. Powers, L., and C. B. Lyon. Inheritance studies on duration of developmental stages in crosses within the genus *Lycopersicon.* Jour. Agr. Res. **63**: 129–148. 1941.
14. Reynard, G. B., and M. S. Kanapaux. Ascorbic acid (vitamin C) content of some tomato varieties and species. Proc. Am. Soc. Hort. Sci. **41**: 298–300. 1942.
15. Rick, C. M. A survey of cytogenetic causes of unfruitfulness in the tomato. Genetics **30**: 347–362. 1945.
16. Stair, E. C., and R. K. Showalter. Tetraploidy in tomatoes induced by the use of colchicine. Proc. Am. Soc. Hort. Sci. **40**: 383–386. 1942.
17. Stebbins, G. L. Types of polyploids: their classification and significance. Advances in Genetics **1**: 403–429. 1947.
18. Suneson, C. A., O. C. Riddle, and F. N. Briggs. Yields of varieties of wheat derived by backcrossing. Jour. Am. Soc. Agron. **33**: 835–840. 1941.
19. Went, F. W. Plant growth under controlled conditions. II. Thermoperiodicity in growth and fruiting of the tomato. Am. Jour. Bot. **31**: 135–150. 1944.

Correction Re Cultivation of Henbane

George M. Hocking

In my article, "Henbane—Healing Herb of Hercules and of Apollo" in ECONOMIC BOTANY **1**: 306–316, 1947, the statements contained in the third to sixth paragraphs, inclusive, under "Cultivation" (p. 308), should be understood only as summarizing orthodox practice up to a very few years ago. Since then the work of A. F. Sievers and M. S. Loman of the U. S. Department of Agriculture[1] in experimental growing of mydriatic drug plants has demonstrated that henbane can be transplanted successfully from pots to the field as readily as can belladonna and that henbane cannot be practically propagated by direct sowing of the seed in the field.

Mr. Sievers (personal communication, Nov. 26, 1947) states: ". . . seedlings . . . were transplanted to the field with practically no loss. What is more convincing, however, are the results obtained by commercial growers in 1942 in a number of States, particularly North Carolina and Wisconsin. I saw one field of at least three acres in which henbane seedlings taken from a seed bed had been set out with a tobacco transplanter in a way which made me certain that the survival would be very small. Many of the plants had hardly been covered at all, others were planted too deep, *etc.* To my great surprise I learned when I visited this same grower later in the year that he got an excellent crop from this field and that very few of the plants failed to live."

Respecting direct sowing of the seed in the field, Mr. Sievers writes: "Perhaps under exceptional conditions where the land is practically free from weed seed due to very clean culture during the preceding years and an unusually fine tilth, direct field sowing might succeed. However, such conditions are rarely met with and our observations have been that the tender seedlings before they are an inch high will be destroyed by flea beetles, potato beetles, and other insects unless extreme vigilance is practiced and such depredations reduced to a minimum through repeated applications of efficient insecticides. Not only this but the much faster growing weeds present an almost impossible job of hand weeding that would be very expensive."

[1] Jour. Am. Pharm. Assoc., Sci. Ed. **33**: 45–56. 1944.

Fifty Years of Quantitative Microscopy in Pharmacognosy

J. HAMPTON HOCH
School of Pharmacy, Medical College of the State of South Carolina, Charleston, S. C.

As an applied science pharmacognosy utilizes many techniques and procedures originated or developed by ancillary sciences. Sometimes such techniques have been modified to better meet the peculiar needs of pharmacognosy, and the development of quantitative microscopical methods is a case in point.

The selection of 1897 as a starting point for this review of some of the highlights of quantitative microscopical methods in pharmacognosy is purely arbitrary.

Initial attempts by several analysts[1] to utilize the microscope for quantitative evaluation and determination of foods and spices and drugs antedate the publications of Kebler and LaWall, of Sayre, and of Kraemer which appeared in 1897. Kraemer's application of a comparative counting method for powdered cloves (1894) and Day's counting chamber method for powdered elm bark (1895) were used to determine starch adulteration and represented the early attempts by American pharmacognosists to apply quantitative microscopical procedures to control of powdered drugs.

Fifty years ago, for approximate starch determination in powdered opium, Kebler and LaWall (1897) counted the granules in a fixed area, averaging the results of three or four mounts, and comparing with similar mounts prepared from various concentrations of the pure starch until the number of granules was the same in both cases.

Kraemer's procedure (1897) was vastly more refined and emphasized proper sampling, identical fineness and treatment of unknown and standard, uniformity of cover glasses, homogeneous mixture, and uniform volumes of mounts. By designating five areas in five fields in at least a dozen mounts of both unknown and standard, accuracy of the count was increased. Only approximately quantitative results were claimed for this procedure of comparing unknown powders with mixed powders of known percentage composition.

A different application of microscopical procedure by Sayre (1897) to distinguish Alexandrian and Indian sennas included a comparative count of trichome tips in the powdered drugs.

The use of exact numerical designations for expressing measurements of histological elements is a phase of quantitative pharmacognosy which was developing at this time in America as well as in Europe, but this review will not include it.

In 1901 Meyer in his "Grundlagen" proposed methods which served as a basis for the further development of quantitative counting methods. The use of a counting chamber of fixed volume and the determination of the normal count ("Normalzahl") of starch grains were elaborated and extended to a variety of vegetable powders. The necessity of selecting easily recognized, well-defined elements of fairly uniform size such as starch, pollen and aleurone grains, stone cells, trichomes, *etc.*, was pointed out by Meyer (1909) for the determination of the percentage of any drug powder in a mixture. He devised two forms of me-

[1] Cleaver, Stuart, Bell, Weinzierl and others.

chanical stage for facilitating strip counts across the mount and prescribed the determination of the "normal count" for a given weight (1 mgm.) of a material against which the count of a known weight of the sample could be compared and percentage calculated.

The next development by Hartwich and Wichmann of a special counting chamber in which a weighed amount of powder and a definite volume of liquid were introduced came in 1912. These workers also took cognizance of the variable moisture content of air-dried starches and deduced the weight of individual granules of several kinds of starch. By determining the equivalent weight of each unit counted in pure material they calculated its percentage in any mixture of which it was a component.

In 1915 Chamot discussed procedures for quantitative analysis with the microscope, calling attention again to the importance of uniform distribution in the mount and of the specific gravity of the components. He had earlier (1909) suggested plotting counts against percentages for a straight line function to check the accuracy of the work and to serve as a standard chart for subsequent determinations of the same components. The advantages of an ocular micrometer with net rulings were stressed by Chamot, and the determination of volume and weight per cents from area measurements as employed in petrography (since 1847) were indicated.

The use of a planimeter for area measurements by Weinzierl (1887) and Kraemer's suggestion (1894) of cutting out and comparing weights of desired tissue areas in photomicrographs had not yet been adopted in quantitative pharmacognosy.

Weinwurm (1898), Ewell (1898), Koenig (1903), Hartwich (1906), Huss (1906), Hanausek (1907), Haertel and Will (1907), Ezendam (1909), Bredemann (1911), Vauflart (1911) and Oerum (1912) were some of the workers who applied quantitative microscopic methods to various food products. In addition to those already mentioned, Linde (1911), Wasicky and Wimmer (1915), Trottner (1915), Bruijning (1915), and Lehmann and Trottner (1917) extended the procedures to examination of drugs.

Wallis' introduction of the lycopodium method in 1916 marks the beginning of what might be termed the modern history of quantitative counts in pharmacognosy. Wallis pointed out the sources of error in different manipulations and the absence of any exhaustive investigation of the relative worth of common methods. By eliminating the necessity of exact volume measurements or any special counting chamber, the use of lycopodium spores as an "indicator" diluent was a simpler procedure suggested by the bacteriologists' use of blood as a diluent for counting bacteria in vaccines. The requirements for suitable suspending liquids were formulated by Wallis. As a control he suggested that two sets of counts of ten fields each should not vary more than 10% and he estimated the error of this method to be less than 10%. In determining 94,970 as the number of spores of lycopodium per milligram, Wallis (1919) established a fundamental datum for his method.

Schneider (1920*a*) described a general method of procedure using a special fixed volume counting chamber with #80 powders, although he favored the hemacytometer for very fine powders or starches. Fifty to a hundred counts from ten to twenty fields were recommended, and the structural elements upon which to base counts for various drugs were listed by Schneider. He also called attention to the errors resulting from the lack of usable records of the quantitative tissue variations in plants. In counting starch granules Schneider (1920*b*) advised counting aggregates as

one, and he gave a list of starch counts, granules per gram, as tabulated by Berger.

The small number of European and American pharmacognosists working in quantitative microscopy were hindered by the lack of fundamental and reliable data on which to proceed, and Wallis (1921) called for a limitation of effort to materials promising satisfactory results and for the elaboration of a universally acceptable method of procedure which would not require special stages, slides or other appliances and which would be suited to a wide variety of substances. The unreliability of published values for the number of starch grains per milligram was pointed out, and the utility of the lycopodium method was emphasized.

In his "Analytical Microscopy" Wallis (1923) formulated the aim of quantitative microscopy as the measurement of mass, either by counting the number of particles of a particular kind or by measuring the superficial area of portions having a definite thickness and a known density. Counting methods, he felt, were more generally serviceable.

The status of counting methods in quantitative microscopy 23 years ago was discussed at the Plant Science Seminar meeting in Buffalo where Keenan (1925) stated "it is surprising what accurate and trustworthy results may be obtained on certain classes of products by experienced workers" and concluded, "Much work remains to be done along this line". The Bureau of Chemistry methods used for flour and for pyrethrum flowers were described at this meeting and the essentials for concordant results were discussed.

Seven years later Wildman's publication (1931) on an application of statistical analysis to sampling relations in quantitative microscopy appeared. This work showed that sampling error was no greater than in macroscopic methods of analysis.

A development essentially identical with Wallis' lycopodium method was Heilborn's (1931, 1933) use of powdered quartz for counting characteristic plant cells. His derivation of comparison number ("Vergleichzahl") and normal count ("Normalzahl") were not new, although extension to the total cell number of an entire plant organ ("Organzahl") was unique. In calling attention to the phenomenon of eutely or cell constancy of plant tissues and the relations between eutely and polyploidy Heilborn pointed out the consequences for quantitative microscopic analysis of drug powders.

Wallis (1935), attempting to further simplify his counting procedure, devised a counting field finder which eliminated the need for a mechanical stage. Affixing this ruled card to a plain stage served as a guide for proper spacing of counting fields.

A count of pericyclic sclerenchyma cells in ipecac stems by the lycopodium method was published in 1938 by Lupton. To avoid large groups of cells he used a #90 powder subjected to a crude fiber process and counted cells and spores in scans rather than a number of fields. Lupton noted the necessity of adjusting the relative number of spores and cells within reasonable limits and the fact that large errors creep in when the cells are too few and scattered.

The recommendation of Flueck and Haller (1945) that quantitative estimation of the purity of powdered drugs be included in the pharmacopoeia is based on the successful results which different workers have obtained with various microscopic procedures. Wallis' lycopodium method was modified in some details by Flueck and Haller in the procedure they recommended for the Swiss pharmacopoeia.

Area Measurements. Hart in 1919 had applied to several drug powders an area method, determining the area of

certain tissue fragments with ocular and stage micrometers, in preference to counting methods. Her procedure, based on relative areas and not relative weights of the components, was not adopted by other pharmacognosists. But Wagenaar (1929), using an area method, weighed known amounts of powdered sample on a slide, and with a calibrated cover glass measured and estimated the total surface of certain tissue fragments of the adulterant. By comparison with data previously established for the adulterant alone, percentages as low as 1.5% were determined with an error claimed to be only .05% to .15%. The eye-estimation of the area of small fragments was a weak point of Wagenaar's method.

It was in 1933 that Wallis and Saber introduced area determination with lycopodium count for the quantitative measure of leaf epidermis, finding that epidermal area gave a good indication of the weight of powdered leaf present in an admixture. Area variations resulting from preliminary treatment and mounting were considerable. Camera lucida tracings on millimeter-ruled paper were preferred to weighing paper outlines or using the planimeter. Saber (1934) considered this method to have an extreme limit of error of 15%.

The effect of common methods of comminution and of some reagents on area determinations of leaf epidermis in senna were subsequently studied by Saber (1937) who found that losses of 8.%, 10.5% and 13.6%, respectively, resulted with hand mortar, disintegrator and end-runner mills, because these amounts of epidermis became unrecognizable. Soaking in water increased epidermal area data as much as 16%, and clearing in chloral hydrate solution caused an additional 3% increase.

Fairbairn's work (1943) on the cells per unit area in the sclerenchyma layer of cardamom seeds yielded results accurate within 3% to 8%. He used the camera lucida and weighing of paper drawings to calculate the number of cells per square millimeter, and determined his standard error by statistical methods.

The term "histometric index", introduced by Cortesi (1943), is the area ratio existing between various tissues, *e.g.*, cork and fibers, as determined by measuring the projected image of a transverse section.

Palisade Ratio. Zoernig and Weiss (1925) first called attention to the fact that the average number of palisade cells beneath an upper epidermal cell afford a useful diagnostic character. Wallis and Dewar (1933), in applying this finding to *Barosma* species, determined the palisade ratio from groups of four contiguous epidermal cells. In the next ten years the palisade ratio was investigated by numerous pharmacognosists, among them Dewar (1933, 1934) for *Digitalis* species; Markwell and Cross (1935) for spearmint and ailanthus; Wallis and Forsdike (1938), Feinstein and Slama (1940), and Bogarosh (1943) for some solanaceous leaves; Ullrich (1943) for some labiate drugs; and George (1943) for senna.

The lack of constant increase or decrease in palisade ratio from base to apex or from midrib to margin led these workers to conclude that variation is independent of position on the leaf. Likewise the variation seemed not to depend on age of leaf, habitat in which grown, or crop year. Two camera lucida tracings, one of epidermal cells and a second of underlying palisade, can be superimposed, counting only those palisade cells of which more than half the area lies under the epidermal cells. Leaf segments two to three mm. square from the central area, removed as far as possible from veins, are preferred. George (1943) applied statistical analysis to his results and confirmed the desirability of making counts from groups of four epidermal cells.

Vein Islet Number. In 1929 Levin introduced the term "vein islet number" as the number of vein islets per square millimeter of leaf surface, and investigated its taxonomic value for *Barosma* species. Excluding regions near mid-rib and margin or near base or apex he found most constant figures in the central portion of the lamina and concluded that the relatively small variation within a species permits the distinction of certain leaf drugs from the same genus, *viz.*, *Cassia*, *Erythroxylon*, *Digitalis*. Levin's projection method was simplified by Zufall and Burlage (1932) who counted all the vein islets in a field of known area, and from the average area of an islet calculated the vein islet number for some *Mentha* and solanaceous species. Feldman and Youngken (1944) showed that lower values resulted from the direct microscopic count than with projection or camera lucida methods.

Stomatal Index. For pharmacognostical diagnosis stomatal dimensions were used by Kimura and Fujikawa (1931) and Flueck (1931) as well as by the English workers.[2] Likewise counts of stomata, expressed as the number per square millimeter of leaf surface, were applied to drug plants by Timmerman (1927) and Dewar (1933 and 1934).

Salisbury (1927) had proposed a "stomatal index" to represent the proportion of stomata to ordinary epidermal cells in a unit area, and Rowson (1943) studied its application to the cogeneric species yielding senna, belladonna and coca. He found stomatal numbers of little value for species differentiation, but since the number of epidermal cells varied similarly the stomatal index was relatively constant. Direct counts were made of all stomata and epidermal cells in a field of fixed area, eliminating cells of the extreme margin and above the midrib. From counts at the mid-area the number per square millimeter was calculated and the index figure derived. Statistical analysis of variance confirmed the significance of stomatal index. Rowson claimed accuracy for this procedure, even with finely powdered material.

[2] Wallis and Dewar (1933), Dewar (1933 and 1934), Markwell and Cross (1935).

Finally mention should be made of Wallis and Fairbairn's (1943) use of the lycopodium method to determine the percentage of powdered nux vomica in medicaments, measuring the length of lignified rib from the epidermal trichomes. An error of less than 2% results if the pure powdered nux vomica is subjected to the same processes as the medicament.

Refinement of quantitative microscopical methods utilized in pharmacognosy has resulted from study of variable factors in both the procedures and the materials investigated. Statistical analysis of the data obtained with improved techniques justifies an increased attention to this phase of pharmacognosy.

References Cited

1887—Weinzierl, T., Zeits. Nahr. Unters. Hyg. **1**: 117–126.

1894—Kraemer, H., Proc. Am. Pharm. Assoc. **42**: 159–167; Am. Jour. Pharm. **66**: 479–86.

1895—Day, W. B., Proc. Am. Pharm. Assoc. **43**: 200–203.

1897—Kebler, L. F. and LaWall, C. H., Am. Jour. Pharm. **69**: 244–250.

—Kraemer, H., Am. Jour. Pharm. **69**: 523–533; Proc. Am. Pharm. Assoc. **45**: 215–219.

—Sayre, L. E., Am. Jour. Pharm. **69**: 298–307.

1898—Ewell, E. E., Jour. Appl. Micr. **1**: 122.

—Weinwurm, Zeits. Unters. Nahr. Genussm. **1**: 98.

1901—Meyer, A., Die Grundlagen und die Methoden für die Mikroskopische Untersuchung von Pflanzen-pulvern, pp. 125–137.

1903—Koenig, J., Chemie der menschlichen Nahrungs- und Genussmittel, vol. 1.

1906—Hartwich, C., Zeits. Unters. Nahr. Genussm. **12**: 525.

—Huss, H., Landw. Vers.-Sta. **60**: 1.

1907—Hanausek, T. F., Microscopy of Technical Products, transl. by A. L. and K. B. Winton.

—Haertel, F. and Will, R., Zeits. Unters. Nahr. Genussm. **14**: 567.
1909—Ezendam, J. A., Zeits. Unters. Nahr. Genussm. **18**: 462.
—Chamot, E. M., 7th Int. Congr. Appl. Chem., C, 249.
—Meyer, A., Zeits. Unters. Nahr. Genussm. **17**: 497.
1911—Bredemann, G., Landw. Vers.-Sta. **75**: 134–157.
—Linde, O., Apoth. Zeit. **26**: 136.
—Vauflart, Ann. Falsif. **4**: 381.
1912—Hartwich, C. and Wichmann, A., Arch. Pharm. **250**: 450–471.
—Oerum, H. P. T., Biochem. Zeits. **35**: 18–28.
1915—Bruijning, F. F., Pharm. Weekblad **52**: 273–293, 309–333.
—Chamot, E. M., Elementary Chemical Microscopy, pp. 205–216.
—Trottner, K., Arch. Pharm. **253**: 92–102.
—Wasicky, R. and Wimmer, C., Zeits. Unters. Nahr. Genussm. **30**: 25–27.
1916—Wallis, T. E., Analyst **41**: 357–375; Pharm. Jour. **97**: 467.
1917—Lehmann, F. and Trottner, K., Repert. Pharm. **28**: 49.
1919—Hart, F., Jour. Am. Pharm. Assoc. **8**: 1032–1034.
—Wallis, T. E., Pharm. Jour. **103**: 75–76.
1920*a*—Schneider, A., Jour. Am. Pharm. Assoc. **9**: 1140–1153.
b—Schneider, A., Microbiology and Microanalysis of Foods, pp. 92–103, 125–127.
1921—Wallis, T. E., Jour. Am. Pharm. Assoc. **10**: 249–252.
1923—Wallis, T. E., Analytical Microscopy, pp. 126–137.
1925—Keenan, G. L., Jour. Am. Pharm. Assoc. **14**: 112–113.
—Zoernig, H. and Weiss, G., Arch. Pharm. **263**: 451–470.
1927—Salisbury, E. J., Phil. Trans. Roy. Soc. London, B, **215**: 1–65.
—Timmerman, H. A., Pharm. Jour. **118**: 241.
1929—Levin, F. A., Quart. Jour. Pharm. Pharmacol. **2**: 17–43.
—Wagenaar, M., Zeits. Unters. Lebensm. **57**: 413–418, 525–537; Pharm. Weekblad **66**: 1021–1025, 1185–1202.
1931—Flueck, H., Pharm. Acta Helv. **6**: 125.
—Heilborn, O., Svensk Bot. Tid. **25**: 185.
—Kimura, K. and Fujikawa, F., Jour. Pharm. Soc. Japan **51**: 105–108.
—Wildman, J. D., Jour. Assoc. Official Agr. Chem. **14**: 563–570.
1932—Zufall, C. J. and Burlage, A., Jour. Am. Pharm. Assoc. **21**: 330–333.
1933—Dewar, T., Quart. Jour. Pharm. Pharmacol. **6**: 443–453.
—Heilborn, O., Svensk Bot. Tid. **27**: 161–201.
—Wallis, T. E. and Dewar, T., Quart. Jour. Pharm. Pharmacol. **6**: 347–362.
—Wallis, T. E. and Saber, A. H., Quart. Jour. Pharm. Pharmacol. **6**: 655–668.
1934—Dewar, T., Quart. Jour. Pharm. Pharmacol. **7**: 1–22, 331–345.
—Saber, A. H., Quart. Jour. Pharm. Pharmacol. **7**: 161–166.
1935—Markwell, W. A. N. and Cross, A. E., Analyst **60**: 748.
—Wallis, T. E., Analyst **60**: 520.
1937—Saber, A. H., Jour. Egypt. Med. Assoc. **20**: 111–116.
1938—Lupton, A. W., Quart. Jour. Pharm. Pharmacol. **11**: 225–233.
—Wallis, T. E. and Forsdike, J. L., Quart. Jour. Pharm. Pharmacol. **11**: 700–708.
1940—Feinstein, B. S. and Slama, F. J., Jour. Am. Pharm. Assoc. **29**: 370–371.
1943—Bogarosh, P. L., Am. Jour. Pharm. **115**: 373–385.
—Cortesi, R., Pharm. Acta Helv. **18**: 361.
—Fairbairn, J. W., Quart. Jour. Pharm. Pharmacol. **16**: 243–249.
—George, E., Quart. Jour. Pharm. Pharmacol. **16**: 226–232.
—Rowson, J. M., Quart. Jour. Pharm. Pharmacol. **16**: 24–31, 255–64.
—Ullrich, G., Am. Jour. Pharm. **115**: 196–206.
—Wallis, T. E. and Fairbairn, J. W., Jour. Royal Microscop. Soc. **63**: 1.
1944—Feldman, H. S. and Youngken, H. W., Jour. Am. Pharm. Assoc. **33**: 277–288.
1945—Flueck, H. and Haller, V., Pharm. Acta Helv. **20**: 92–107.

Additional References Not Cited

1908—Meyer, A., Arch. Pharm. **246**: 523–540.
1918—Huss, H., Svensk Kem. Tid. **30**: 227.
1920—Wallis, T. E., Jour. Royal Micr. Soc. Part II, 169–178.
1921—Schneider, A., Microanalysis of Powdered Vegetable Drugs, pp. 93–101, 141–173.
1923—Ezendam, J. A., Pharm. Weekblad **60**: 604.
1925—Pluecker, W., Steinruck, A., Starck, F., Zeits. Unters. Nahr. Genussm. **50**: 307.
1926—Griebel, C. and Sonntag, F., Zeits. Unters. Lebensm. **51**: 185.
1927—Alpers, A., Zeits. Unters. Lebensm. **54**: 462.
—Wagenaar, M., Zeits. Unters. Lebensm. **54**: 357.
1928—Wagenaar, M., Zeits. Unters. Lebensm. **56**: 205.
1932—Edman, G., Svensk Farm. Tid. **36**: 301–306.